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Desulphurisation of Shale-Oils,
Oil Shale Resources,
and
Production of Oil from Cannel Coal
and Allied Minerals.

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

NOTICES.

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Copyright. The entire contents of the Journal are covered by general copyright, and official permission is necessary for reprinting long abstracts; but editors may use not more than three pages of any paper, provided that credit is given as reproduced from the Journal of The Institution of Petroleum Technologists or advance-proofs thereof.

Issue of Journal. The Journal appears in four parts per sessional volume, viz. in December, February, April and June. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed annually by revisions of the Library Catalogue and List of Members.

Members of all classes are entitled to receive these publications free: for additional copies of the Journal they will be charged at the price of five shillings per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel-Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel-post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible; and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of January, March, May or November as the case may be. Subsequent delivery may be too late for insertion.

The Library. In the full catalogue of the Library, published in our brochure of September, are included the titles of such papers in journals received as bear upon any subject within the purview of the Institution. Such titles are not included in the intermediate lists given in our several parts, where, as below, the journals received are acknowledged in single entries.

The attention of such of our members as are authors is directed to the absence of their works from the Library, (with some exceptions), and we shall be particularly thankful for gifts of treatises on special branches of technology, and for separate copies of papers contributed to other Institutions and to journals, either in past or future.

Additions to the Library.

American Academy of Arts and Sciences, Proceedings, vol. liii, pt. 6, 1918.

American Chemical Society. The Journal of Industrial and Engineering Chemistry, vol. x, pts. 5, 6. 1918.

Athenæum Subject Index to Periodicals, 1916. Science and Technology including Hygiene and Sport. Pp. 162. 4to, *London*, 1916.

Blizard, J. The Value of Peat Fuel for the Generation of Steam. *Canada Dep. Mines, Mines Branch, Rep.* no. 447 (*Bulletin* no. 17). 1917.

Buisson, A. The Production of Copper, Gold, Lead, Nickel Silver, Zinc and Other Metals in Canada during the Calendar Year 1916. *Ann. Rep. Min. Prod. Canada*, 1916. *Canada Dep. Mines, Mines Branch, Rep.* no. 471. 1917.

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Casey, J. The Production of Cement, Lime, Clay Products, Stone and other Structural Materials in Canada during the Calendar Year 1916. *Ann. Rep. Min. Prod. Canada*, 1916. *Canada Dep. Mines, Mines Branch, Rep.* no. 470. 1917. *By Exchange.*

Cassier's Engineering Monthly, vol. liii, nos. 5, 6. 1918. *From Arthur W. Eastlake.*

Cole, L. H. Test of some Canadian Sandstones to Determine their Suitability as Pulpstones. *Canada Dep. Mines, Mines Branch, Rep.* no. 466 (*Bulletin* no. 19). 1917.

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Haanel, E. Summary Report of the Mines Branch for the Calendar Year ending December 31, 1916. *Canada Dep. Mines, Mines Branch, Rep.* no. 454. 1917.

Investigation of Bituminous Sands of Northern Alberta (S. C. Ells), p. 56–58. Specifications for the Purchase of Oil (E. Stansfield & V. F. Murray), p. 64. Oil Burette for Fractional Distillation and Specific Gravity Determination (V. F. Murray), pp. 71, 72.

Imperial Institute, Bulletin, vol. xv, nos. 3, 4. 1917.

India, Geological Survey, Records, vol. xlviii, pt. 3. 1917.

Institution of Mechanical Engineers, Proceedings, 1917, pt. 2.

Institution of Mining and Metallurgy, Bulletin, nos. 163, 164. 1918.

Institution of Mining Engineers, Transactions, vol. lv, pt. 2. 1918. *By Exchange.*

Institution of Petroleum Technologists, Journal, vol. iv, nos. 15, 16. 1917. *Native Production.*

James, J. F. Account of a Well drilled for Oil or Gas at Oxford, Ohio, May and June, 1887. *Journ. Cincinn. Soc. Nat. Hist.*, vol. x, pp. 70–77. 1887. *From W. Whitaker.* (Exc.)

Junior Institution of Engineers, Journal and Record of Transactions, vol. xxvii, nos. 8, 9. 1918.

Lindeman, E., L. L. Bolton and A. H. A. Robinson. Iron Ore Occurrences in Canada. *Canada Dep. Mines, Mines Branch, Rep.* no. 217, 2 vols. 1917. *By Exchange.*

Lucey Manufacturing Corporation. Supplement No. 10 to Regulations War Trade Board Export Licenses. Pp. 4. 4to, *New York*, 1918. *From the Lucey Corporation.*

McLeish, J. The Production of Iron and Steel in Canada during the Calendar Year 1916. *Canada Dep. Mines, Mines Branch, Rep.* no. 458. 1917.

—— The Production of Coal and Coke in Canada during the Calendar Year 1916. *Ibid.*, no. 465. 1917.

—— Preliminary Report [on] the Mineral Production of Canada during the Calendar Year 1917. *Ibid.*, no. 478. 1918.

Marine Engineer and Naval Architect, vol. xl, pts. 10, 11. 1918. *By Exchange.*

Noetling, F. The Occurrence of Petroleum in Burma, and its Technical Exploitation. *Mem. Geol. Surv. India*, vol. xxvii, pt. 2. Pp. iv, 226; 18 pls. *From W. Whitaker.*

Oil Age, vol. xii, no. 12: xiii, nos. 1, 2: xiv, no. 4.

Oil and Colour Trades Journal, vol. l, nos. 1020–1028. 1918. *By Exchange.*

Oil News, April 13—June 8, 1918.

Petroleum World, vol. xv, May, 1918. *From Sir Boverton Redwood.*

Royal Colonial Institute. United Empire, n.s., vol. ix, nos. 5, 6. 1918.

Royal Society for the Encouragement of Arts, Manufactures and Commerce, Journal, vol. lxv, nos. 3415—3423. 1918.

Satterley, J. and R. T. Elworthy. Mineral Springs of Canada. Part I.—The Radioactivity of some Canadian Mineral Springs. *Canada Dep. Mines, Mines Branch, Rep.* no. 435 (*Bulletin* no. 16). 1917. *By Exchange.*

Scientific Societies' Conjoint Board. Confirmed Minutes of 7th Meeting, March 13, 1918. Pp. 14. *From the Board.*

Shipbuilding and Shipping Record, May 2–June 27, 1918. *By Exchange.*

Sinclair's Magazine, nos. 9, 10. 1918. *From the Sinclair Refining Co.*

Skinner, W. R. The Oil and Petroleum Manual for 1918. Eighth Year of Publication. 8vo, *London*, 1918. *From the author.*

Smith, P. H. Two Essential Conditions for Burning Tar Oil in Diesel Engines. *Diesel Eng. Users Assoc.* May 16, 1918. Pp. 4.

Society of Chemical Industry, Journal, vol. xxxvii, nos. 8–11. 1918.

United States Patent Office, Official Gazette, vols. 248, 249. 1918. *By Exchange.*

As we go to press we have received, through the kind offices of our Honorary Member Sir Frederick Black, a long series of the Technical Papers and Bulletins of the United States Bureau of Mines. These valuable additions to the Library will be duly listed in our next issue.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry may be inserted in the Journal. Application for terms, etc., should be made to the Secretary.

LIST OF ADVERTISERS.

(Members are desired, when making enquiries or placing orders with advertisers, to mention that they have seen their announcement in the Journal.)

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

We regret to learn of the decease of Mr. S. F. Stackard, upon the 15th May last.

Dr. T. O. Bosworth is again visiting Ecuador.

Prof. John Cadman has received the honour of K.C.M.G.

Mr. A. Lloyd Eastlake, Lieutenant R.E., only son of the Hon. Secretary, has the proud distinction of having been in charge of one of the novel weapons of offence on board H.M.S. "Vindictive" on the occasion of the memorable attack which resulted in the closing of the harbour of Zeebrugge. Mr. Eastlake was fortunate enough to pass through this trying ordeal unscathed, and has been mentioned in despatches by Vice-Admiral Sir Roger J. B. Keyes, K.C.B., C.M.G., C.V.O., commanding the Dover Patrol, for distinguished services on the night of the 22nd–23rd April, 1918.

Mr. C. B. Rosenplaenter left London for Africa at the beginning of the month.

Mr. G. J. Savage is a 2nd Lieutenant in the 5th Reserve Battalion, R.E.

Sir Boverton Redwood, Bart., our first President, in a lecture entitled "The Romance of Petroleum," delivered at the Royal Institution recently, gave much information with regard to the petroleum industry. His discourse was illustrated by a number of lantern slides, and a unique series of models. It is to be regretted that, owing to restriction in the use of paper, full extracts cannot be given, but the following table of the world's production of crude petroleum for 1917, and the remarks accompanying it, will be of interest to our members:

The World's Production of Crude Petroleum for the Year 1917, in Metric Tons.

(*Estimated.*)

Country.	Metric Tons.	Percentage.
United States... ...	45,573,333	64·74
Russia...	9,333,333	13·26
Mexico	8,000,000	11·37
Dutch East Indies ...	1,933,333	2·74
Rumania	1,466,600	2·08
India	1,133,333	1·61
Persia...	933,333	1·32
Galicia	666,666	·947
Japan	433,333	·615
Peru	360,000	·511
Trinidad	213,000	·303
Germany	133,333	·189
Argentine	120,000	·170
Egypt	66,666	·094
Canada	26,666	·037
Italy	5,866	·008
Other Countries ...	4,000	·006
Total metric tons ...	70,403,128	100·000

It will assist us to realise what is needed [for the temporary storage and transport of this large quantity] if I give you some calculations which have been obligingly made for me by Mr. William Sutton.

A vertical cylindrical tank 80 feet in height would need to be 10,952 feet, or a little over two miles in diameter, to hold the world's production of petroleum for last year. Such a tank would cover an area approximately three times that of Hyde Park and Kensington Gardens together.

It would require a pipe 6 feet 2 inches internal diameter, with a rate of oil flow of 8 feet per second, or two miles an hour, delivering continuously throughout the year, to transport the world's production by that means.

The oil would fill over seven million ten-ton railway tank waggons. These would make a train of 28,000 miles in length, considerably more than sufficient to encircle the earth at the equator, and such a train, running at 25 miles an hour, would take 46 days 16 hours to pass a given point.

The world's production of crude petroleum is equivalent to 17 gallons *per capita* of the estimated population of the world.

HOUR OF MEETINGS OF INSTITUTION.

It has been suggested that the meetings of the Institution should be held earlier in the day. It is proposed during the next Session to commence them at 5 p.m. Members are invited to communicate their views to the Honorary Secretary with regard to this change, which is purely a war-time measure.

UNIVERSITY OF BIRMINGHAM.

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The Session commences in October.

Full particulars of the Course can be obtained from the Secretary of the University.

EDITORIAL.

Co-ordination of Scientific Publication.

This was a subject of a recent discussion by the Faraday Society, opened by the President, Sir Robert Hadfield, and participated in by many of the leading scientific and technological authorities. The duplication of work by the learned Societies of the United Kingdom, over 600 in number, and the dissemination of information through their multitudinous publications, often in those least likely to contain such, were advanced as the basis of a proposed Federation, with a central body of referees to receive all communications and decide as to the most useful organ for their publication. The thoroughly representative gathering dissented from the proposition of such centralisation.

One important factor ignored by the propounders of the scheme is that of human nature, of which scientists and technologists alike partake. Their research work is mostly unremunerative, where not wholly gratuitous, and (to paraphrase a hackneyed proverb) they that find the facts have the right to select the medium of promulgation, and to decide upon the extent of detail published. Mere appearance in abstract is not publication, and no one is justified in regarding an abstract as the original communication. Personally, the writer objects to the inclusion, in bibliographical lists or critical references, of abstracts, condensations or unrevised reproductions (reprints, for instance, from the advance-slips which the Institution sends to the Press as "proofs under revision"). Nothing but the finally-revised text is legitimately to be regarded as publication.

Besides the loss of liberty in the respects indicated (which would greatly reduce the publication of discoveries in every branch of science and technology), there falls to be considered the extent of the promulgation effected. Distribution through a wide range of serials may somewhat enhance the labour of literary research, but at the same time, there is reached a vastly wider circle, and the slight knowledge of a subject that would excite interest in a simply-written article would debar its possessor from attempting to follow a more erudite communication. Under the submission to the suggested hierarchy, scientific and technological papers would tend to become a mass of jargon unintelligible to all but initiates of the special cult. Incomprehensible terminology is

as effectual a bar to study as can be any foreign language, involving deeper research than reference to dictionary and grammar.

Communication to bodies not specially or largely devoted to the branch of study including the subject of the paper involves of necessity some rehearsal of fundamental principles and explanation of technical terms, but this popularisation, so far from being regrettable, is really most beneficial. Few, if any, can be masters of every subject that may excite their passing interest, and yet there is no branch of study the devotees of which do not upon occasion absolutely require some insight into cognate branches, without penetrating deeply into any but their speciality. The scheme under discussion would reduce such enquirers to choice between obsolescent serial literature, prior to the scheme, and books, more or less out of date, independent of its restrictions.

A still more serious consideration is that of the ill effect of the power of the proposed Inquisition to suppress heretical works, anything that tended to impugn established views. There would be no power to place books in an *Index Expurgatorius*, but publication in a recognised scientific serial would be impossible, unless indeed the author of the heresy were already one of the elect, in which case the new "doxy" would be described as "epoch-making," even if its duration were as brief as its triumph was easy. A case of the mischievous effect of orthodoxy in science was cited in our article on p. 193 of vol. iii, and doubtless similar illustrations could be adduced from the history of technology.

Co-ordination of data, co-operation of investigators in special lines of study, and conference with those in allied branches are matters the importance of which we have frequently urged in these pages, but the scheme advanced, though not apparently concerned with investigation, would have a directly injurious effect thereupon, however much it reduced the labours of bibliographers.

To repeat a remark in one of the earlier of these editorial articles (vol. i, p. 96), "Let *brains* decide, when doctors disagree: it is a great deal better for the brains than to have their pabulum supplied ready-digested by Pontifical authority as the only orthodox diet."

Thirtieth General Meeting.

This Meeting was held at the House of the Royal Society of Arts, on Tuesday evening, 16th April, 1918, Sir Boverton Redwood, Bart. (Vice-President), occupying the Chair.

The Members of Council present were Professor J. S. S. Brame and Mr. Arthur W. Eastlake. A letter of regret for unavoidable absence was received from Dr. F. Mollwo Perkin.

The Chairman, in opening the proceedings, remarked that the Hon. Secretary had perhaps been a little too optimistic in announcing, on the invitation card, that the chair would be taken that evening by the President. But members would be delighted to hear that Mr. Greenway, who, a fortnight ago, had undergone a serious operation, was making a record recovery. The speaker had seen Mr. Greenway on the previous Saturday, and found him sitting up in bed very bright and cheerful, anxious to hear about the affairs of the Institution.

Members would know, since the announcement had been made in the press, that the Committee to be appointed to deal with the Home Supplies of Oil had been duly constituted, and he understood that the Committee had already met and had made substantial progress in organising the arrangements for carrying out the work entrusted to it.

The following paper was then read by Dr. Dunstan:

Relation between Viscosity and the Chemical Constitution of Lubricating Oils.

By A. E. Dunstan, D.Sc., F.I.C., F.C.S., *Member*, and
F. B. Thole, D.Sc., F.C.S., *Associate Member*.

A study of the published information regarding the chemical structure of the hydrocarbons constituting mineral lubricating oils, and the influence of this molecular structure on the lubricating efficiency of such oils, shows the existence of profound ignorance of the chemistry of the high-boiling components of petroleum, an ignorance particularly regrettable, since the most important properties of such oils, the viscosity, "oiliness" and "gumming" propensities, depend to an exceptional degree on the chemical nature of these components. Our present limited knowledge of the subject is derived principally from the researches of Engler, Kharitchkov, Holde, Nastyukov, and in particular of Mabery and Marcusson. The numbers attached to names of authors referred

to are those of entries in the condensed bibliography at the end of the paper.

It appears beyond doubt that the high-boiling fractions of petroleum, irrespective of their place of origin, are complex mixtures containing but a small percentage of paraffin hydrocarbons of the formula C_nH_{2n+2}, and consisting chiefly of compounds whose formulæ range from C_nH_{2n} to C_nH_{2n-6}. A few of these compounds have been isolated by Mabery[1, 2] by repeated fractional distillation of crude American oils, even from a crude so pronouncedly paraffinoid in nature as Pennsylvanian oil.

The origin of these hydrocarbons has given rise to considerable speculation, though it has afforded but little insight into their molecular structure. Engler and Routala[3] have shown that amylene and hexylene, under the influence of heat and pressure, yield a product rich in naphthenes, similar in appearance and in behaviour on heating to Baku cylinder oil. They consider that the polymerized olefine is an intermediate product in the synthesis. Krämer and Spilker[4] offer a similar suggestion, regarding a polymerized decylene as the intermediate compound, which on decomposition yields a paraffin and a hydrocarbon, $C_{20}H_{38}$, apparently identical with one of the components of Baku oil, $2(C_{10}H_{20})_2 = 2C_{10}H_{22} + C_{20}H_{38}$.

Sabatier and Senderens[5] found that the catalytic action of reduced nickel converted acetylene into products resembling lubricating oil, and suggested their "carbide" theory of the origin of petroleum.

In no case has the chemical constitution of a component of a lubricating oil been established, but the chemical behaviour of these oils indicate that among the components are unsaturated hydrocarbons (possibly open-chain but more probably naphthenic and polynuclear, or perhaps of both types), saturated hydrocarbons (naphthenic and probably to some extent polynuclear, but not to any appreciable extent paraffinoid), and aromatic hydrocarbons (to an unknown and possibly a limited extent), together with small amounts of sulphur- and oxygen-containing compounds, the latter of which can be isolated, and are probably the principal cause of gumming.

The unsaturated compounds constitute between 20 % and 40 % of most lubricating oils, and can be removed from the oil by agitation with concentrated sulphuric acid[6, 7]. Nastyukov[8, 9, 10, 11] has shown that in the presence of sulphuric acid, formaldehyde combines with these hydrocarbons, forming insoluble solid compounds termed "formolites." Instead of formaldehyde, methylal

may be employed[13], and according to Richardson[13] the same absorption is observed whether sulphuric acid or the formolite reagent are employed. Marcusson[14] and Nastyukov agree that American oils contain a higher percentage of these unsaturated hydrocarbons than the corresponding Russian oils. The low iodine-values of lubricating oils, and the susceptibility of these "constants" to variations in the conditions of the test[15] seem to indicate that the unsaturated cyclic compounds attacked by sulphuric acid and by formaldehyde do not react readily nor normally with iodine chloride. The iodine-value of a lubricating oil increases with increasing boiling-point. Marcusson states that after the removal of the unsaturated components of the oil by the formolite reagent or by sulphuric acid the residual oil is richer in hydrogen, and has a higher viscosity (this statement is not in accordance with our own results) and a lower specific gravity than the original material. Analysis indicates that the saturated compounds are principally naphthenic, and most probably poly-nuclear in structure[17], since they contain less hydrogen than is demanded by the simple naphthenic formula C_nH_m. Krämer and Spilker[18] studied the effect of heat and pressure on Baku cylinder-oil, on some synthetic aromatic hydrocarbons of high viscosity which they considered typical of the more viscous components of lubricating oil[19], and on rosin oil rich in open-chain olefinic hydrocarbons. The two latter classes gave products rich in anthracene, while Baku oil gave naphthalene, but no anthracene derivatives. They concluded, therefore, by a process of elimination, that the hydrocarbons of Baku lubricating oil are essentially cyclic compounds, and not polymeric olefines nor aromatic compounds.

Nothing appears to be known regarding the possible presence of aromatic compounds, though Brooks and Bacon[20] have isolated from lubricating oils a minute quantity of material which is the cause of fluorescence or "bloom," and which on this account is (according to modern theories) necessarily aromatic in nature.

The resinous components have been shown by Holde[21] to be present to the extent of a few parts per cent., and to be capable of separation from the hydrocarbons by treatment with alcohol and ether. They are solid, oxygen-containing lac-like bodies, and are probably the principal cause of "gumming," since they would tend to accumulate as the hydrocarbons in the oil evaporated. Moreover, the hydrocarbons thus purified showed no tendency to gum on prolonged exposure to heat and air.

The actual influence on the viscosity of the oil of the differences in chemical nature of the different components has been stated

by several workers, the statements being in some cases contradictory. Mabery and Mathews[22] have published figures which indicate conclusively that an increase in viscosity occurs concurrently with a decrease in the hydrogen-content, paraffins being comparatively very mobile, while hydrocarbons of the formula C_nH_{2n-4} are as viscous and as efficient in lubricating power as sperm oil. These investigators as the result of experiments with testing machines also demonstrate that the durability of an oil film is directly connected with the viscosity of the oil, a view in accordance with that of Künkler[23], who in fact urges that viscosity *per se* is of minor importance, but is of great service as an indicator of the vitally important quality of "adhesion."

Marcusson[14, 17] has determined the physical properties of lubricating oils before and after removal of the unsaturated components by means of the "formolite reagent." He considers that the unabsorbed, i.e. saturated naphthenic compounds are the essential lubricating constituents of the oil. This conclusion is not in accord with those of Nastyukov and other workers[5] on the subject, and requires further investigation.

The influence of physical conditions on the viscosity of lubricating oils, especially as regards preliminary heat treatment, was pointed out long ago by Bender[24], while the recognition of colloidal components in machine oil by Schneider and Just[25] brought lubricating oil into line with other colloids as regards the characteristic manifestation of viscosity-hysteresis.

The Determination of Viscosity.—When a sequence of experimental operations has to be carried out, and when the supply of material is limited, the usual commercial methods which are adopted for the determination of viscosity are impracticable. Consequently, in this investigation we have used the methods which we have adopted during the past fourteen years for the elucidation of the connection between chemical constitution and viscosity. In brief, the Ostwald apparatus, modified in a few details, has been made use of[26]. By means of this instrument we have investigated the viscosity of so small an amount as 0·2 cc., but for ordinary purposes its capacity may well be 10 cc. The viscometer is clamped in a vertical position in a thermostat, maintained at any desired temperature by means of a Lowry toluene-filled thermo-regulator. The temperature can readily be kept within $\pm 0°{\cdot}01$ C. When it is remembered that the temperature-coefficient of viscosity ranges upwards from 2 % per 1° C., it is obvious that rigorous thermo-regulation is all important.

The viscometer is filled with the filtered oil, particular care

being taken to avoid the choking of the capillary by particles of dust. After standing in the thermostat for 15 minutes at the selected temperature, the levels of the oil are adjusted to the etched marks by means of a capillary pipette. The liquid is drawn up above the upper mark by suction, and the time of flow to the lower mark is taken by means of a chronograph, which is from time to time checked against a standard clock. Usually 4 or 5 times are taken and averaged. The mean error in this determination is approximately 0·1%.

To obtain the absolute viscosity from the time of flow, the constant of the viscometer and the density of the oil must be known.

When a liquid flows under its own hydrostatic pressure through a capillary tube, the following conditions being assumed—

(*a*) there is no slip at the surface of the capillary;

(*b*) there is steady flow, no eddies, nor turbulent motion;

(*c*) there is no kinetic energy of efflux;

then the transpiration formula becomes,

$$\eta = \frac{\pi}{8}\left[\frac{hgr^4}{l \times v}.d.t.\right] \text{ where}$$

η = absolute viscosity in dynes per sq. cm.
h = head of liquid in cms.
g = gravitation constant.
r = radius of the capillary in cms.
d = density of the liquid at the temperature of the experiment.
t = time of flow in seconds.
l = length of the capillary in cms.
v = volume of liquid transpiring in the time t.

A correction-term, viz.—$\frac{v}{8\pi l}.\frac{d}{t}$ is usually introduced to compensate for the loss of kinetic energy of efflux.

For small pressures, high viscosities, and narrow capillaries, the correction tends to become vanishingly small, and may in many cases be neglected.

For any given viscometer, the above formula resolves itself into:

$$\eta = A.d.t. - B\frac{d}{t}, \text{ where A and B are}$$

constants, and if the dimensions are so chosen that the kinetic energy-correction term is unnecessary, then the formula simplifies to η = A.d.t. where A is the viscometer-constant.

For further details in connection with the various viscosity-formulæ, and the corrections thereto, the reader is referred to a comprehensive paper by Bingham and White[27].

In working with an instrument of the Ostwald type, it is

necessary to determine the value of A, the viscometer-constant. This may readily be accomplished by means of some liquid the viscosity and density of which are known. For an oil-viscometer which must necessarily possess a capillary of at least 1 mm. bore, a viscous calibrant is required. Such a liquid is sulphuric acid[15]:—

Viscosity of Sulphuric Acid.

Temperature.	100 %.	99·8 %.	98·2 %.	96 %.
13·8° C.	0·360	0·342	—	—
25·0°	0·235	0·224	0·220	0·190
50·0°	0·106	0·102	0·0954	0·0943
70·0°	0·0685	0·0657	0·0598	—
90·0°	0·0425	0·0410	0·0403	0·0399

Archbutt and Deeley recommend aqueous glycerol solutions, of known concentration. Other obvious materials are aqueous sucrose solutions[16], or oils which have been already examined in a previously calibrated viscometer. This latter method has been used in the determinations in this present communication, seeing that a very carefully calibrated instrument was in our possession. As a standardising medium, we chose medicinal paraffin. The following measurements indicate the procedure:—

Time of flow at 25° C. of medicinal paraffin in previously calibrated viscometer:—9359 seconds.

density at 25° C:—0·8738

log. constant of viscometer $\bar{5}\cdot7380$

Hence, since $\eta = \text{K.d.t.}$,

$$\log.\ \eta = \bar{5}\cdot7380 + \bar{1}\cdot9414 + 3\cdot9719 = \bar{1}\cdot6463$$

$$\therefore\ \eta = 0\cdot443$$

Time of flow in oil viscometer (bulb = 10 cc.; length of capillary = 12 cm.; bore 0·1 cm.) was 90·4 seconds, therefore, since $\eta = \text{K.d.t.}$, $0\cdot443 = \text{K} \times 0\cdot8738 \times 90\cdot4$, and $\log.\ \text{K} = \bar{3}\cdot7487$.

Representation of Viscosity Results.—Seeing that in this country viscosities are usually quoted in terms of Redwood's, in the States in terms of Saybolt's, and on the Continent in terms of Engler's standard instruments, it is necessary to find some factor for interconversion. In a paper by McIlhiney[17], the equivalents of Redwood, Saybolt and Engler have been published in tabular form, with, in addition, the corresponding absolute viscosity. The term centipoise has been coined to express conveniently the quantity 0·01 in absolute viscosity. Hence a viscosity of ·51 is 51 centipoises. The name is derived from Poiseuille, the eminent pioneer of the practice of viscometry.

Most conveniently, 0·01 dynes per square cm. is the absolute viscosity of water at 20° C.; so that centipoise units also measure

specific viscosities in terms of water at 20° C. as a standard substance.

Attention must here be drawn to one further point: for mobile oils, of which the transpiration-time is rapid, anomalous results are found, due to the kinetic energy of efflux being neglected in the viscometer-constants. This difficulty can be surmounted by determining the constant by means of several liquids of known viscosity, and plotting the constants thus obtained against time of flow. A regular curve results from which the appropriate constant for any given transpiration-time can be read off[30].

Relations between Temperature and Viscosity.—A variety of expressions has been put forward to connect viscosity and temperature, e.g.,

Poiseuille's formula $\eta_t = \eta_0 (1 + \alpha t + \beta t^2)$, α and β being constants.

O. E. Meyer's „ $\eta_t = \eta_0 / (1 + \alpha t)$

Slotte's „ $\eta_t = \frac{C}{a + t} - \delta$ and $\eta_t = \eta_0 / (1 + \beta t)^n$

The last-named formula was selected by Thorpe & Rodger in their classical memoir on viscosity. Unfortunately the expression only holds good for non-associated, simple liquids, and it breaks down on being applied to lubricating oils. Some years ago the present authors developed the view that logarithms of viscosity were much more additive than viscosities themselves. Thus, whilst the viscosity-concentrates curve of a liquid mixture is never exactly linear, and frequently diverges very much from linearity, the logarithmic curve is always nearer to the straight line. Arrhenius[31] and Kendall[32] have also put forward logarithmic formulæ for mixtures. Esling was able from his own data to confirm the validity of this idea[27].

Now, if the logarithms of viscosities are plotted against temperature, the hyperbolic viscosity-temperature curve approaches linearity, and the resulting graph is easier to interpret, seeing that the temperature-coefficient remains constant over a reasonably large temperature-range.

Log. viscosity-temperature coefficients are shown in figs. 8–12. For complete references to the technique of viscometry, see the authors' monograph on the Viscosity of Liquids, 1914.

Effect of Chemical Constitution on Viscosity.—Viscosity is the expression of a dual phenomenon; there is first of all the mechanical friction of molecule against molecule, and this must depend upon relative molecular surface and molecular volume; then there is the resistance to deformation brought about by the mutual attraction of the molecules for one another. It follows that viscosity

must be largely a constitutive property, and will be influenced considerably by molecular structure and arrangement.

In the case of lubricating oils derived from petroleum, we have to deal with somewhat carefully refined hydrocarbons, and the three constitutive variables that concern us are unsaturation, conjugation and symmetry.

Unsaturation or the presence of latent valency has in general the effect of raising viscosity. For example, phenyl ethane $Ph \cdot CH_2 \cdot CH_3$ has viscosity at 25° C. 0·00607; phenyl ethylene $Ph \cdot CH : CH_2$, 0·0111.

Far more striking, however, are the effects produced by the alternation of double and single linkings of carbon atoms (the "conjugated double bonds" of Thiele).

		Viscosity.
Acetone...	... $CH_3 \cdot CO \cdot CH_3$	·00305
Mesityl oxide	... $\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!C=CH \cdot CO \cdot CH_3$	·00876
Phorone...	... $\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!C=CH-CO-CH<\!\!\begin{matrix}CH_3\\CH_3\end{matrix}$	·0189

By combining the effects of conjugation of double bonds with the conjugation of unsaturated groups, a very great exaltation of viscosity is observed. Finally, a symmetrically-distributed molecule possesses a less viscosity than one markedly unsymmetrical.

It should further be observed that in colloidal emulsoids there is deformation during the passage through the capillary, causing an increase in surface. Hence surface energy is created, masquerading as viscosity in the ultimate value which is determined.

The Examination of the Viscosity of Mineral Lubricating Oils.—The first point of interest is that practically every grade between extreme mobility and extreme viscosity can be obtained from suitable fractions of petroleum, since the viscosity is a function of molecular weight, and the crude petroleum is a mixture of homologous series of hydrocarbons varying in molecular weight from 16 to several hundreds.

The desideratum for a lubricant is that as low a viscosity as possible should be accompanied by good lubricating power and great stability. These three factors must be discussed in detail.

The lowest viscosity compatible with circumstances is essential, because otherwise energy is absorbed needlessly and converted into heat. The lubricant is concerned with the transformation of solid into liquid friction, and therefore its own internal friction must be as near zero as possible.

On the other hand, the vital importance of maintaining the film of lubricant between shaft and bearing necessitates that mysterious property known as "body." Perhaps no property has been discussed so assiduously amongst lubrication-experts as this. Archbutt and Deeley refer to it as "oiliness," and endorse the opinion of Wilson that, in reality, oiliness or body is a function both of viscosity and capillarity. Unfortunately there is little experimental record on the surface-tension of mineral oils, but there is a very close relationship between the two properties to which reference has been made. Both are conditioned by the play of inter-molecular forces, and both are intimately affected by association and unsaturation.

Oil possessing a lower surface-tension than metal flows over and covers a bearing; water would behave similarly. Under working conditions, the film of water would be squeezed out, the oil-film remains. The surface-tension of water is greater than that of oil, but its viscosity is very much smaller. The oil forms a thicker film, which resists attempts to deform it. Similarly, a soap solution, although of lower surface-tension, resists rupture more successfully than does pure water.

Kingsbury[83] in an investigation on oiliness and viscosity, points out that whilst mineral oils possess less body than the animal or vegetable oils, yet the different oils tested by him exhibited body in the same order as viscosity.

Künkler[84] urges strongly that of all the necessary qualities of a lubricating oil the chief is "adhesion" or film strength, viscosity playing a minor part. The "adhesion" of a mineral oil however is greater the more viscous the oil, and viscosity determinations are therefore of value as an indirect method of ascertaining the "adhesion" quality of the oil.

Mabery[85] also emphasizes the importance and the elusiveness of this capacity for building a stable film, but prefers to determine it by direct examination on a Carpenter testing machine, measuring the "durability" of the oil by investigating the duration of efficient lubrication after the oil supply is shut off.

Richardson and Hanson[86] consider that no mechanical testing-machine meets all the conditions required. Further, seeing that at 400°–500° F. all oils, good or bad, approximate to the same viscosity, they place little reliance upon this property. They emphasize the need of some method of determining "film-tension," but admit that such a method is difficult to find. They advocate the importance of investigating the physical constants of the oil before and after exposure to air at a constant high temperature, and in a thin film.

Sir Boverton Redwood's views in connection with the testing of lubricating power are strongly in favour of the validity of viscosity as against mechanical tests, although, as he points out, the latter have demonstrated that there is the closest relation between lubricating power and viscosity.

Whilst, undoubtedly, all the evidence goes to show that body and viscosity run closely parallel in the case of lubricating oils, yet this is by no means universal for all substances, as witness the high viscosity of aqueous sucrose and glycerol solutions. We feel that some other more definite criterion is needed, and we propose to combine with viscosity the determination of surface-tension, adopting for the measurement of the latter property the weight of a falling drop[66]. The apparatus is eminently simple, and seems, so far as our preliminary experiments go, to yield fairly accurate figures.

It is not improbable that some connection exists between body and molecular weight. When it is realised that the triglyceryl-ester of ricinoleic acid, which is present in castor oil, has a molecular weight of 932, whereas that of Russian engine oil is 426 and of Chesebrough vaseline 646, it is reasonable to expect a much higher value for the molecular volume in the fatty oil. This enhanced value shows itself not only in high viscosity but also in "oiliness."

The question of molecular volume brings us to another consideration. Recent work on colloid chemistry points to the fact that heavy oils must be included in the category of iso-colloids, i.e. polyphase systems in which the disperse component is of the same chemical nature as the dispersion medium. Just as water must be regarded as a system in which molecules such as $[H_2O]_2$ coexist with simple H_2O molecules, so in a lubricating oil the disperse phase is a molecular aggregate suspended in a dispersion medium of simpler and similar structure. It is certain that this conception materially assists our efforts to explain the high viscosity, the large temperature-coefficient of viscosity, and the hysteresis effects which have been observed in heavy oils. The high coefficient may be due to two causes, (*a*) the increasing dispersity of the disperse phase, (*b*) the lowering of interfacial tension.

Granted that lubricating oils are iso-colloids, then this mysterious oiliness or body may merely be the effect of the degree of dispersion exhibited by the particular oil.

The possession by lubricating oils of hysteresis-phenomena alluded to above is confirmed by the work of Glazebrook[67], who has obtained results similar to those of the present authors.

On no other grounds than those provided by the theory of the colloidal state can these examples of hysteresis be explained. The phenomenon is one eminently characteristic of colloids. It can be produced at will repeatedly, and is bound to play a great part in the general development of the theory of oil chemistry. Signs are not wanting that at length the value of pure colloid investigations is being appreciated in many directions, notably in the rubber, artificial silk, leather, textile, and pottery trades: it is not too much to prophesy that the oil-refining industry will one day be controlled by colloid-chemistry.

It is an interesting side issue to note the applications of colloids already in the oil world, as witness the preparation of lubricating greases, the decolorisation of distillates by colloidal earths, the manufacture of vaseline and lubricating oils, the breaking up and the formation of emulsions, the use of strong sulphuric acid in refining, and the utilisation of colloidal graphite in oil-dag and aquadag.

Little need be said on the subject of stability. Saponification, which is an ever-present risk with a vegetable or animal oil, cannot occur in the case of a mineral oil. The chemical sluggishness of high molecular weight hydrocarbons makes them resistant in a high degree to oxidation. Obviously a paraffinoid oil would be ideal from this point of view, but unfortunately such oils possess little lubricating value. The addition of solid paraffin to an oil will, in fact, diminish its viscosity considerably. The figures for paraffin wax on p. 215 bring out this point very clearly.

Mabery[2] has clearly demonstrated this point by comparing the viscosities of pairs of different types of hydrocarbons possessing the same boiling-points.

Hydrocarbon.		Sp. Gr.		Viscosity.
C_nH_{2n+2}	...	·781	...	10·88
C_nH_{2n-2}	...	·841	...	21·23
C_nH_{2n+2}	...	·775	...	8·51
C_nH_{2n}	...	·835	...	15·63

Durability machine-tests indicated that the smaller the hydrogen content, the greater was the durability and the viscosity.

It is the polynuclear naphthenes, above all the unsaturated components of an oil, which confer viscosity and body, and luckily, as any given petroleum is distilled, the tendency is for the lower fractions to be saturated, yielding good petrol and burning oil, whilst the higher fractions become more and more unsaturated. The wax is merely a survivor of the paraffin series, being accom-

panied by large amounts of naphthenic saturated and unsaturated hydrocarbons.

If any of the lubricating oil fractions be examined, it is found to contain both saturated and unsaturated compounds. The latter may be extracted by means of a large excess of sulphuric acid. The resulting saturated hydrocarbon is invariably of a higher molecular weight, but lower in density, and lower in viscosity; the acid has removed the chief lubricating components. (Reference should here be made to an important paper[4] which has appeared whilst this communication was going through the press.)

The method we have adopted in this examination is as follows: 50 cc. of the oil are diluted with 50 cc. of petroleum ether (B.P. below 60° C.), mixed with 100 cc. of sulphuric acid, and agitated vigorously on a shaking machine for two hours. At the end of this time, the mixture is placed in a separating funnel, and the acid tar run off. Usually this sets to a solid or semi-solid mass. The etherial solution is well washed with water, then with aqueous ammonia, finally with water, dried over calcium chloride, and the ether removed in a vacuum.

The viscosity and density of the filtered oil are determined in the usual way and plotted out for various temperatures on squared paper. Several such graphs are here appended.

The mean molecular weights of the oils before and after treatment were determined by the depression of freezing-point of pure naphthalene. Duplicate determinations usually agreed to one or two units. It will be noticed on examination of any of the graphs that—

(1) The viscosity of the original oil is higher than that of the treated oil throughout the whole range of temperatures.

(2) The viscosity-curves tend to approach each other at high temperatures.

(3) The specific gravity of the treated oil is considerably lower than that of the original oil.

(4) The log. viscosity-temperature curves are nearly linear over a wide range of temperature, and

(5) They tend also to intersect at high temperatures.

Besides determination of viscosity, density and molecular weights, ultimate analyses for carbon and hydrogen were carried out. Both Mabery and Krämer at various times have spoken of the difficulties in accomplishing the combustion of a heavy oil. We also have found that these difficulties are serious, and the combustion-tube must not only be well packed with copper-oxide and lead chromate, but also "tuned up" so that the oxidising agents are in good

condition. In some cases, the failure to get carbon and hydrogen to amount to 100 % must be ascribed to the presence of sulphur, oxygen and nitrogen in the oil. On one occasion we traced the presence of free sulphuric acid, and more than once the occurrence of perceptible mineral ash. Usually, however, the figures were obtained in near proximity to 100 %.

Krämer and Spilker[19] quote two analyses which illustrate this difficulty :—

	Russian Lubricating Oil.		Pechelbronn Oil.	
C	86·36	86·84	86·34	86·87
H	11·80	12·04	12·51	12·61
	98·16	98·88	98·85	99·48

Having determined the ultimate analysis, the construction of an empirical formula with the help of the mean molecular weight can be attempted. It must, however, be clearly borne in mind that such formulæ are merely the average of those of a number of dissimilar substances, and only give an approximate idea of the average ratio of carbon atoms to hydrogen atoms.

It is convenient to remember that the lower paraffins (C_1H_{12} — C_9H_{20}) possess the carbon percentages 83·3 to 84·4 ; the members C_9H_{20}—$C_{12}H_{26}$ give the figures 84·4 to 84·7, whilst the higher homologues ($C_{13}H_{28}$ to $C_{22}H_{64}$) show the numbers 84·7 to 85·3.

It will be noted that none of the oils examined by us is paraffinoid.

Further, the cyclo-paraffins and olefines C_nH_{2n} always possess the composition C=85·7 %, H=14·3 %, irrespective of their molecular weight. Persian no. 7 approximates to this.

It should be noted that Engler and Jezioranski[7] have also determined the ultimate analysis and absorption by strong sulphuric acid, but not specifically in lubricating oils. Some of their figures may be quoted :—

	Galician Crude Oil.	Fraction under 150° C.	Fraction 150°–200° C.	Residue above 200° C.
% C	86·2	85·35	85·45	87·35
% H	13·8	14·65	14·55	12·65
% soluble in C.O.V. ..	49·8	17	23	completely soluble.
Volume of Fraction ..	100	41	21	38
	Sumatra.			
% C	85·6	85	86·2	87·1
% H	14·2	15	14·0	12·85
% soluble in C.O.V. ..	23·8	16	28	36
Volume of Fraction ..	100	54		

	Pennsylvanian Crude Oil.	Fraction under 150° C.	Fraction 150°–200° C.	Residue above 200° C.
% C	86·1	85·3	85·3	86·8
% H	13·9	14·9	14·65	13·2
% soluble in C.O.V.	28	16	18	85
Volume of Fraction	100	14	26	60

It is interesting to observe the progressive unsaturation as the boiling-point rises.

The formolite value of an oil has been put forward by Nastyukov in a series of papers as a discriminatory test between the saturated and unsaturated components of an oil. The details of the test are well known. Methylal $CH_2(OMe)_2$ has been proposed by Heer[12] as a more sensitive condensing agent; it probably has a similar action to that of formaldehyde. That portion of the oil which is unacted upon by the reagent is said to contain the olefines, alicyclic saturated hydrocarbons and naphthenes, but seeing that strong sulphuric acid is used in the test, it is difficult to see how the olefines escape, and further to see precisely what action the formaldehyde has, over and above that of the acid. Nastyukov suggests that, owing to condensation, complex saturated hydrocarbons are formed—it is well known, for instance, that benzol yields diphenyl methane. If this is so, then the final oil residue does not represent merely a residual oil unacted upon by the reagent, but also contains certain reaction-products.

Marcusson, following up this work, concludes that the lubricating properties of mineral oils are due to those hydrocarbons which are inert to formaldehyde and sulphuric acid, and that the reactive components possess a higher specific gravity, and a lower viscosity than the original oil; conclusions diametrically opposed to those which we ourselves bring forward. In brief, we find that it is precisely the reactive hydrocarbons which possess superior viscosity.

The following data quoted by Marcusson are typical:—

Russian engine oil gave 17 % as formolite. Sp. gr. before, ·909; sp. gr. of residual oil, ·906. Iodine number before, 5; of residual oil, 1·4. Viscosity before, 42·5 Engler; of residual oil, 64·2.

Analysis before,		of residual oil,	
C = 85·79 %		C = 85·41 %	
H = 12·78 %		H = 13·07 %	
	98·57 %		98·48 %

Further evidence of the essentially unsaturated nature of these oils is afforded by the well-known iodine and bromine numbers. Although probably no very precise significance can be placed on these figures, seeing that they are so affected by manipulative

details and environment, yet in a qualitative sense they indicate clearly enough that a good lubricating oil must not be either paraffinoid or naphthenic in constitution. For example, Radcliffe and Polychronis[15] have shown that the Hübl, Wijs and Hanus methods give entirely discordant values, but nevertheless they point indisputably to the fact that residual affinity is a characteristic of a lubricating oil.

	Sp. gr. 15·5°.	Hübl.	Wijs.
American Lubricating Oils.			
Cylinder Oil ..	·875	10·2	22·8
Valve Oil ..	·895	10·6	24·5
Russian Lubricating Oils.			
Cylinder Oil ..	·914	9·9	22·0
Engine Oil ..	·904	6·4	16·8
Spindle Oil ..	·899	4·5	14·4
Scotch Oils.			
Lubricating Oil A	·873	31·6	56·8
B	·890	24·5	49·8
C	·925	19·5	43·6

It is highly interesting to notice that the iodine value, as we should expect, rises as the molecular weight increases, and that the Scotch oils, with their high carbon/hydrogen ratio, should possess the highest values of all. The above authors point out the importance of deciding the possible connection between iodine value and the sludging of a transformer oil.

It appears, then, that the true lubricant is an unsaturated compound, possessing all the attributes of such a compound, i.e.:

(1) capacity to absorb iodine, bromine, oxygen and so on;
(2) solubility in strong sulphuric acid;
(3) higher C/H ratio than the saturated derivative.

Apparently the same facts hold good in regard to fatty lubricants. Rape oil, castor oil and olive oil contain in their molecules double bonds, and are superior in body and viscosity to such a saturated product as, for example, tallow. The objection might be urged that a blown oil (which is less unsaturated and highly polymerized) does not fulfil these requirements, whereas it is notably possessed of excellent body and viscosity. The answer to this is that not only is a blown oil of great molecular weight, but also the hydroxyl groups in it are themselves potential centres of unsaturation.

In recent years, the progress of organic chemistry has largely been due to the realisation that unsaturation, or the possession of residual affinity, plays an all-important part in the reactivity and

the very personality of a compound. Colour, odour, taste, physiological activity, and, in a word, all the characteristic properties of bodies are influenced by this condition. It appears now that we may add lubricating ability to the already long list of effects proceeding from this one prime cause.

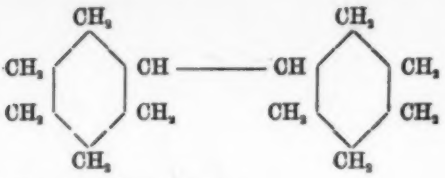
Summing up, we arrive at these conclusions: (*a*) A lubricating oil should contain a certain proportion of unsaturated hydrocarbons —and as large a proportion as is compatible with not too much susceptibility to oxidation, polymerization, gumming and reactivity. Dilution with saturated hydrocarbons undoubtedly does interfere with this display of chemical activity, but the diluent in no way assists lubrication.

If these unsaturated hydrocarbons are (as is probably the case) polynuclear and naphthenic in type, one would expect this reactivity to be almost negligibly small, an expectation which is confirmed by the very low iodine value which mineral lubricating oils possess. In this case there is but little fear of oxidation to gummy products. Holde[21] in fact considers that the cause of gumming is the small amount (up to 3 %) of oxygen-containing resinous matter which accumulates owing to the evaporation of the hydrocarbons. This resinous matter is insoluble in 70 % aqueous alcohol and in alcohol-ether, while the hydrocarbons of the lubricating oil, freed by this method from the resin, show practically no gumming tendency, even under stringent tests. If this view is correct, acid treatment of lubricating oil in the course of its production should be reduced to a minimum, since it tends to remove not only the harmful resins, but also the unsaturated hydrocarbons, which are valuable on account of their high viscosity and body.

(*b*) The physical condition of a good lubricant is probably colloidal. Now, unsaturated compounds possess a great tendency to associate into complexes, therefore there is a distinct probability that such a condition is a normal state of affairs in any lubricating oil.

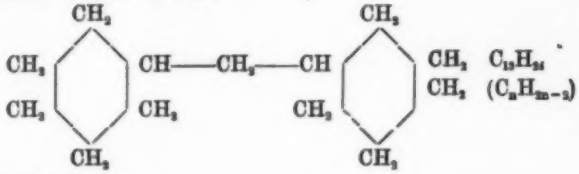
An interesting sidelight on this point is afforded by Lewkowitch's observation that the molecular weight determinations of olive, rape and castor oils vary considerably, depending on the concentration of the solution used[22]. Granted that the original oil is an iso-colloid, then the "true" molecular weight is very high, but on dilution, the colloidal complexes become smaller, and the mean molecular weight naturally also diminishes.

It is a matter of extreme interest to speculate on the probable structure of a hydrocarbon inert to large excess of sulphuric acid (4 parts by weight), and which has a formula such as C_nH_{n-2}. A feasible view is that two polymethylenic nuclei are united, thus:—



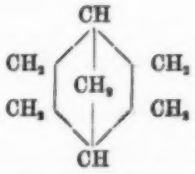
$C_{12}H_{22}$
C_nH_{2n-2}

or via a methylene group:—



$C_{13}H_{24}$
(C_nH_{2n-2})

or a bridged ring:—



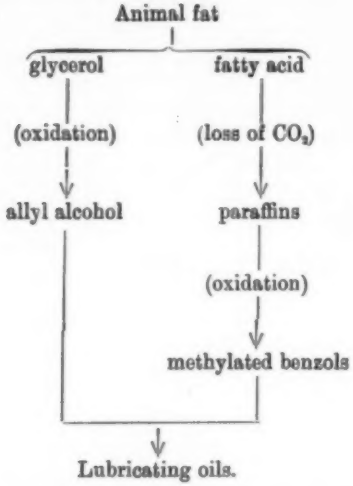
The latter type of structure probably does exist in the unsaturated hydrocarbons, since the acid tar from the heavy oils frequently possesses a most marked terpene-like odour. The saturated hydrocarbons with formulæ containing still less hydrogen may possess aromatic nuclei attached to naphthenic nuclei, or they may consist of complex systems of fused naphthenic nuclei.

In this connection, the views of Krämer and Spilker[29] possess considerable interest. These authors have synthesized condensation-products from methylated benzines and allyl alcohol, which possess extremely high viscosity, and are in fact synthetic lubricating oils. For example, with mesitylene as a starting-out material, they have made:

$$Me_3C_6H_2 - \underset{\displaystyle Me}{\overset{\displaystyle Me}{\overset{|}{\underset{|}{C}}}} - C_6H_3Me_3 \text{ or } C_{21}H_{28} \text{ i.e. } C_nH_{2n-14}$$

This compound has a specific viscosity of over 700. They consider that such bodies are the true "viscosity carriers" in lubricating oil, and that the high viscosity is due to the accumulation

of methyl groups. Highly interesting, too, is their opinion on the origin of such bodies in petroleum:—



In this connection the work of Engler is of the first importance. In a series of masterly researches he and his collaborators have traced the gradual dehydrogenation of paraffinoid into unsaturated hydrocarbons[3]. Heat and pressure combine to transform paraffins into lower paraffins and olefines. The latter condense to poly-olefines, and with further elimination of hydrogen, the poly-olefines yield naphthenes, and lubricating oils. Oils rich in naphthenes are usually found to be rich in lubricating oils and *vice versa*. Experimentally these views were confirmed by heating Baku cylinder-oil under pressure to 400° C. The product was fractionated, and the lighter components were almost entirely paraffins, but as the boiling-point rose, so the proportion of naphthenes increased. The highest-boiling constituents were lubricating oils. Further, the condensing action of aluminium chloride on amylene in the cold yields an oil containing more than 87 % of carbon—possessing the mean composition indicated by the formula C_nH_{2n-6}, and agreeing in properties with natural lubricating oil.

TEMPERATURE COEFFICIENTS.

Russian Oil.

Temperature.	Viscosity from Curve.	Temperature Interval.	Fall in Viscosity.	Percentage Fall per 1° C.
20	2·98			
		20—30	1·64	5·5
30	1·34			
		30—40	·58	4·3
40	·76			
		40—50	·32	4·2
50	·44			
		50—60	·18	4·1
60	·26			

Persian Oil no. 14.

30	·80			
		30—40	·30	3·75
40	·50			
		40—50	·135	2·7
50	·365			
		50—60	·105	2·9
60	·260			
		60—70	·070	2·7
70	·190			
		70—80	·055	2·9
80	·135			

Persian Oil no. 14 after Oleum Treatment.

30	·70			
		30—40	·42	5·7
40	·28			
		40—50	·09	3·2
50	·19			
		50—60	·065	3·4
60	·125			
		60—70	·045	3·6
70	·080			
		70—80	·030	3·7
80	·050			

Persian Oil no. 7.

30	·174			
		30—40	·054	3·1
40	·120			
		40—50	·038	3·2
50	·082			
		50—60	·021	2·56
60	·061			
		60—70	·013	2·14
70	·048			

Persian Oil no. 7 after Sulphuric Acid Treatment.

30	·148			
		30—40	·043	2·9
40	·105			
		40—50	·028	2·7
50	·077			
		50—60	·019	2·5
60	·058			
		70—70	·013	2·25
70	·045			

Persian Oil no. 1.

30	·0365			
		30—40	·0081	2·2
40	·0284			
		40—50	·0050	1·76
50	·0234			
		50—60	·0038	1·64
60	·0196			
		60—70	·0024	1·23
70	·0172			
		70—80		

Temperature.	Viscosity from Curve.	Temperature Interval.	Fall in Viscosity.	Percentage Fall per 1° C.
		Burman Oil no. 7.		
30	·36	30—40	·14	3·9
40	·22	40—50	·075	3·4
50	·145	50—60	·041	2·8
60	·104			
		Burman Oil no. 7 after Sulphuric Acid Treatment.		
20	·414	20—30	·156	3·76
30	·268	30—40	·088	3·3
40	·180	40—50	·060	3·3
50	·120	50—60	·036	3·0
60	·084			
		Burman Oil no. 6.		
20	·310	20—30	·118	5·8
30	·192	30—40	·060	3·1
40	·132	40—50	·040	3·0
50	·092	50—60	·029	3·1
60	·063			
		Scotch Shale Oil.		
20	·498	20—30	·190	3·8
30	·308	30—40	·098	3·2
40	·210	40—50	·068	3·2
50	·142			
		Scotch Shale Oil after Sulphuric Acid Treatment.		
20	·414	20—30	·144	3·5
30	·270	30—40	·090	3·3
40	·180	40—50	·053	3·0
50	·127			
		Vaseline.		
50	·650	50—60	·210	3·2
60	·440	60—70	·140	3·2
70	·300	70—80	·090	3·0
80	·210			
		Glycerol.		
30	4·0	30—40	2·0	5·0
40	2·0	40—50	1·0	5·0
50	1·0	50—60	·45	4·5
60	·55	60—70	·20	3·6
70	·35			
		40 % Aqueous Sucrose.		
20	·062	20—30	·019	3·1
30	·043	30—40	·013	3·0
40	·030	40—50	·007	2·3
50	·023	50—60	·005	2·2
60	·018			

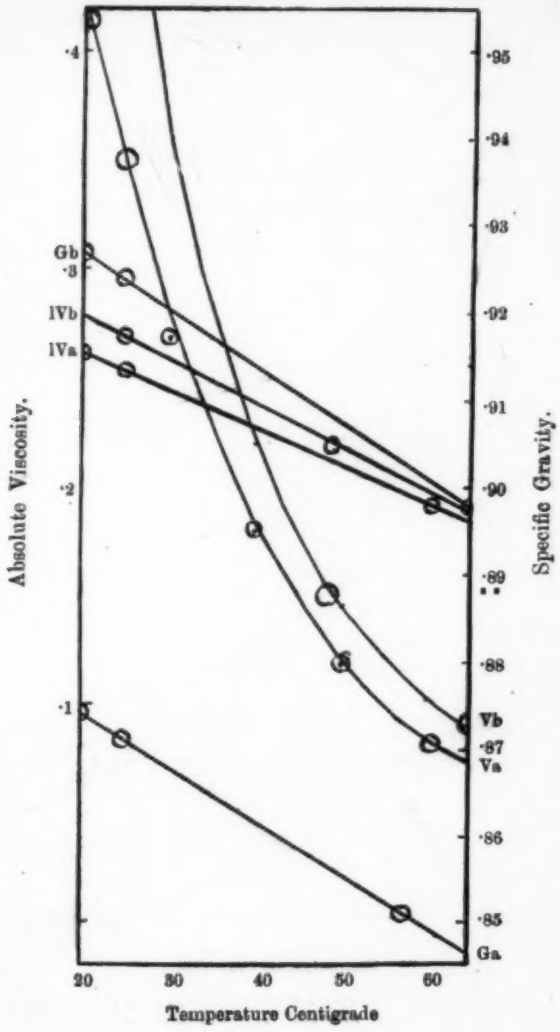
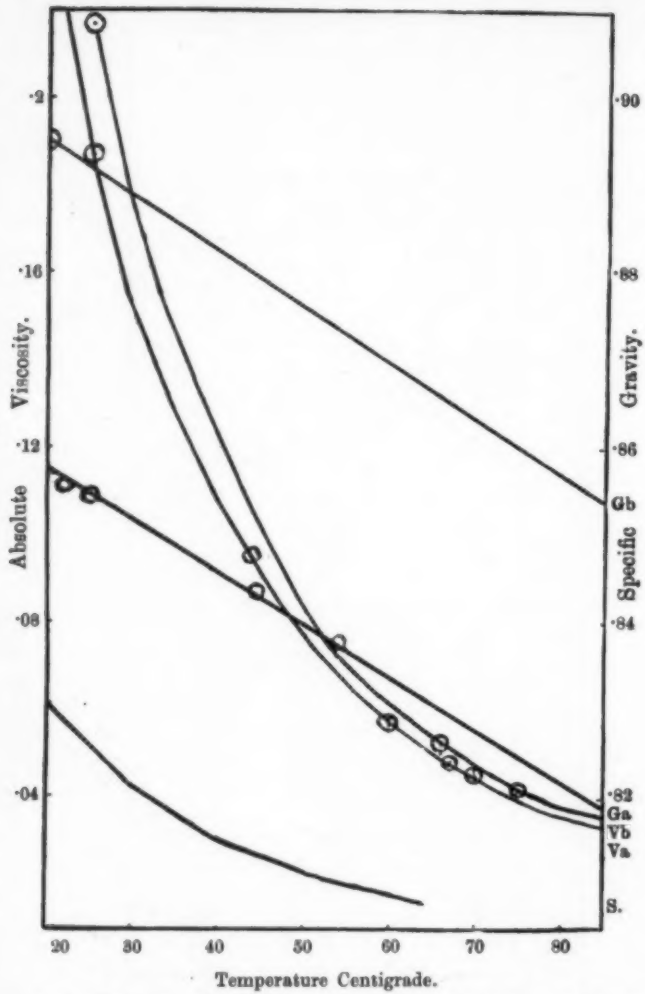


FIG. 8. Burman no. 7.



In these diagrams, G = Specific Gravity curve; Va, Vb, those of Viscosity after and before treatment with C.O.V.: l = logarithms; S, Sugar solution, 40 %.

FIG. 9. Persian no. 7.

FIG. 12. Russian Oil.

FIG. 11. Vaseline.

FIG. 10. Scotch Shale Oil.

PERSIAN NO. 14.

Temp. C.	Absolute Viscosity.	Specific Gravity.	Molecular Weight (mean of 2 results).	Percentages. C.	Percentages. H.	Ratio. C./H.	Approximate Formula.
25°	1·108	·9170	371	85·7	12·84	·55	$C_{27}H_{50}$ (C_nH_{2n-4})
40°	0·484	·8995					
78°	0·1347	·8799					

PERSIAN NO. 14 TREATED WITH 2 VOLUMES OF 3 % OLEUM.

25°	0·525	·8550	430	86·1	13·95	·515	$C_{31}H_{60}$ (C_nH_{2n-2})
40°	0·258	·8445					
65°	0·1025	·8270					

PERSIAN NO. 14 TREATED WITH 2 VOLUMES C.O.V.

25°	0·742	·8738	451	85·93	13·3	·538	$C_{32}H_{62}$ (C_nH_{2n-2})
45°	0·192	·8458					
68·5°	0·135	·8459					
57·5°	0·166	·8507					

PERSIAN NO. 1.

25°	0·043	·8492	232	86·06	13·0	·552	$C_{20}H_{38}$ (C_nH_{2n-2})
30°	0·0368	·8460					
40·5°	0·0288	·8380					
55·0°	0·0208	·8280					

PERSIAN NO. 7.

25°	0·2165	·892	310	86·00	12·95	·554	$C_{22}H_{42}$ (C_nH_{2n-2})
65·7°	0·05215	·866					
67·2°	0·0462	·865					
75·1°	0·0416	·860					

PERSIAN NO. 7 TREATED WITH 2 VOLUMES OF C.O.V. (LOSS = 33·3 %).

25°	0·1875	·8546	357	85·9	14·03	·51	$C_{25}H_{48}$ (C_nH_{2n-2})
43·8°	0·0944	·8435					
60·4°	0·0573	·834					
69·5°	0·0452	·8280					

RUSSIAN LUBRICATING OIL.

20°	2·990	·9092	426	86·4	13·5	·532	$C_{30}H_{58}$ (C_nH_{2n-2})
25°	2·025	·9054					
35·8°	0·984	·8977					
44·3°	0·601	·894					
55·0°	0·379	·889					

RUSSIAN LUBRICATING OIL TREATED WITH 2 VOLUMES OF C.O.V. (LOSS = 20 %).

20°	2·38	·898	451	86·6	13·3	·543	$C_{32}H_{62}$ (C_nH_{2n-2})
25°	1·68	·894					
67·6°	0·189	·869					

SCOTCH SPINDLE OIL.

20°	0·498	·898	346	87·5	12·3	·593	$C_{25}H_{44}$ (C_nH_{2n-6})
25°	0·399	·8954					
43·2°	0·1835	·884					

SCOTCH SPINDLE OIL TREATED WITH 2 VOLUMES OF C.O.V. (LOSS = 50 %).

20°	0·415	·8616	437	86·7	13·2	·547	$C_{31}H_{58}$ (C_nH_{2n-4})
25°	0·337	·8584					
46°	0·148	·845					

BURMAN NO 7.

20°	—	·927	311	88·2	11·75	·625	$C_{22}H_{38}$ (C_nH_{2n-6})
25°	0·488	·9238					
48·4°	0·1508	·909					
65°	0·0859	·898					

BURMAN NO. 7 TREATED WITH 2 VOLUMES OF C.O.V.

Temp. C.	Absolute Viscosity.	Specific Gravity.	Molecular Weight (mean of 2 results).	Percentages. C.	Percentages. H.	Ratio. C./H.	Approximate Formula.
20°	·414	·8741	373	85·9	13·7	·523	$C_{27}H_{50}(C_nH_{2n-4})$
25°	·350	·8710					
37·4°	—	·8510					
61·3°	·0805	—					
			CHESEBROUGH VASELINE.				
44°	·910	—	646	86·3	13·5	·532	$C_{45}H_{90}$ (C_nH_{2n})
48·3°	·7095						
58·1°	·481						
73·0°	·264						
			PARAFFIN WAX, M.P. 105° F.				
55·5°	·0481	—	362	85·55	14·45	·493	$C_{26}H_{54}(C_nH_{2n+2})$
51·7°	·0518						
48·5°	·0598						
			GLYCEROL (FOR COMPARISON).				
25°	5·79	1·256					$C_3H_5(OH)_3$
52°	0·841	1·240					
62·5°	0·497	1·236					

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DISCUSSION.

The Chairman observed that so high was the level of papers read before the Institution since its inception that he had sometimes felt the need, in making criticisms at their meetings, of their guarding themselves against the charge of being a "Mutual Admiration" Society. That consideration, however, should not hinder the bestowal of unstinted praise where it was due. He would therefore characterise the paper just read as a thoughtful, original, eminently practical and altogether masterly treatment of the subject.

It was high time that lubricating oils were so dealt with, because, as the authors pointed out, the prevailing ignorance of the subject was little short of a national disgrace. As an outcome of the authors' researches he hoped that there was now within measurable distance of evolution, a scheme of examination, physical and chemical, of lubricating oils which would enable the commercial analyst to act

as a real guide to the users of petroleum products. Everyone who had had much experience in analytical work of the kind, when called upon by Government Departments, Steamship Companies, Railway Companies, and those responsible for the lubrication of the machinery of great industrial establishments, must have realised how little actual help it was possible to give.

It was true that the purchaser of a lubricating oil could be told whether an oil which had been offered to him in substitution for one in use was similar in physical properties. But if the analyst were cautious and self-respecting he would hesitate to say which of the two oils—assuming there were certain differences—would be found the better for the purpose. As a result, users of lubricants had largely been thrown into the manufacturer's hands, and been compelled to rely upon the reputation of the vendors in the selection of the oils required. It was obviously inconsistent to devote a large amount of attention to obtaining the highest efficiency from fuel if effective means were not, at the same time, taken to guard against the loss of a portion of the power so obtained, by the adoption of an unsatisfactory system of lubrication. The paper which the authors had presented might easily become epoch-making, leading, as it did, to an entirely new outlook upon the factors governing the selection of a lubricating oil.

He would be glad if Dr. Dunstan would, on behalf of himself and Dr. Thole, say something more as to the extraordinary efficiency of sperm oil as a lubricant. The speaker would like to know whether the researches of those chemists had led them to form any conclusion which might be taken as explanatory of the characteristics of sperm oil, in relation to its high lubricating value, as compared with similar factors in mineral lubricating oils. The authors had briefly referred to sperm oil as follows: "While hydrocarbons of the formula C_nH_{2n-4} are as viscous and efficient in lubricating power as sperm oil." It would be instructive and interesting if Dr. Dunstan could make such an addition to that reference in the light of the knowledge he had gained, as he felt justified in putting before the members.

The Chairman next read the following letter from **Mr. N. A. Anfilogoff**:—

I have read the paper with interest, and only regret that I may be unable to be present to take part in the discussion, and add my meed of the praise the authors so richly deserve.

They may, however, in their researches ere long find reliable and definite chemical relationship between the constitution of a lubricating oil and its lubrication value, and work out tests which will

enable the chemist, definitely, to ascertain and advise his engineer confrère on the relative merits, as lubricants, of a whole series of oils which may be submitted to him to adjudicate on.

Mechanical testers have for various reasons not proved an unqualified success, and concordant results for tabulation are difficult to obtain.

The conditions under which the lubricant has to perform its functions are different from those obtaining in a mechanical tester, and the inequalities of bearing expansions and altered friction conditions are bound to give fictitious values.

The only trade and chemical test relied on at present to denote a lubricating value, is viscosity, and that in my opinion can only be useful sometimes to give comparative values with a standard article.

The generic term of Cylinder Oil is applied equally to the oil used in a modern high-pressure superheated-steam cylinder and in the internal combustion cylinder. Yet an oil suitable for the one and in some cases having similar tests, may not be at all suitable for the other.

All refined oils, however divergent their viscosities at lower temperatures, have almost an equal viscosity at 350° F. Only a difference of 2 seconds in Redwood No. 1 Viscosimeter has been noted by me in a series of tests on a number of oils when tested at 350° F., and even this small difference disappears at 400° F. Viscosity, like specific gravity, can be calculated and pre-arranged on blending two oils, and therefore in my opinion neither the one nor the other can be reliable tests for a lubricant. A mixed oil consisting of oils possessing a lesser and greater fluidity, would make a worse lubricant, though having the same viscosity tests as those possessed by a straight run distillate.

In my opinion, *boiling-points*, *vapour tension*, and *film stability*, should prove the only reliable tests of a lubricating oil, though, of course, many of the existing physical and chemical tests could be useful as a guide to the chemist.

Molecular weight by itself, on the other hand, does not always conclusively prove definite virtue as a lubricant, when it is taken into consideration that Russian engine oil gives 426 against 646 for vaseline, since the latter is certainly not the better lubricant.

I do not absolutely agree with Marcusson that only the saturated compounds form the lubricating constituents of an oil, nor would the unsaturated compounds by themselves necessarily give a valuable lubricating oil, as some of the unsaturated constituents are caused by cracking, and form the gum-depositing constituents of a lubricating oil.

With the most careful distillation (even *in vacuo* and presence of steam) slight cracking results, and the cracked condensed vapours dissolve in the lubricating distillate, lowering the viscosity and density. The refiner is "up against it" to try to remove these cracked constituents, if possible selectively, and a small amount of acid used would fairly succeed if the consumer had not been educated up to a "pale" oil. To achieve the colour scheme, the refiner too often uses an excess of acid, which also removes a considerable amount of other unsaturated constituents, with undoubted sacrifice so far as the lubricating value is concerned.

Prof. J. S. S. Brame observed that the work of the authors on viscosity in relation to pure chemistry was well known to most members, particularly in regard to the effect of constitution on viscosity, and the paper furnished a striking illustration of the correlation between pure and applied chemistry, while it emphasised the absolute inseparability of the scientific and practical sides. The Institution was fortunate in that men of the authors' high attainments as pure chemists should turn to the technical aspect of oils and apply their knowledge, largely derived from a study of the phenomena of purely chemical substances. He thought the interdependence of the practical and scientific sides of things could not, in these days, be too strongly emphasised. He had little criticism or comment to make on the paper. The property of "oiliness," referred to in the paper, was one of the most puzzling of the properties of oils. By some it was regarded as unnecessary to connect it with viscosity directly, since it was possessed in a much greater degree by some fixed oils than by many mineral oils which had practically the same viscosity. Again, some bodies were highly viscous, and yet quite undistinguished in the property of oiliness. It might be admitted, with Künkler and others, that viscosity was a minor thing in itself, and that the important and primary factor was the maintenance of the film, the cohesion of the oil. Yet he thought there could be no question that, in the case of oils, the two things went more or less together, and there was an intimate connection between them. He considered the authors' suggestion of a form of apparatus in which they proposed to determine the viscosity, and at the same time obtain data relating to surface-tension, would yield results of great interest, and probably throw light on the question of oiliness. The Institution would look forward to a future paper by the authors when they had obtained the necessary data.

The question of colloids had received some attention from oil

chemists, and was certainly one of the most remarkable of the recent developments in science; extending knowledge of colloids was throwing light on a number of hitherto obscure problems. Dr. Dunstan had ably illustrated the point in the case of oil. There was really no other explanation of the hysteresis noted in the viscosity curves.

One important point the authors had not mentioned, viz., that an oil left for a considerable length of time at a low temperature developed a "network," and its viscosity was found to have increased tremendously. If the oil were disturbed, the viscosity figure would be different. That point was well recognised in Sir Boverton Redwood's method of testing the viscosity of oils under Admiralty specifications, where the oil had to remain for a long period at a low temperature, without being disturbed before the test was made. The speaker believed that in that case the results were undoubtedly due to the association in the same colloidal condition as indicated by the authors. The authors had given several illustrations in their paper of the application of colloidal chemistry in the oil industry, and with the extension of the knowledge of colloids light would be thrown on many problems connected with the industry. Indeed, he did not think there was any branch of technical chemistry where the application of colloidal chemistry was likely to be of more service.

The authors had ascribed lubricating value primarily to the presence of unsaturated hydrocarbons of the polynuclear or naphthenic type—therein differing from some others; but the speaker considered the authors' case a good one, and its practical bearing was contained in a suggestion made in the paper—to reduce to a minimum the acid treatment of lubricants. Mr. Anfilogoff referred to the point in his letter, and remarked that the producer was hampered by the fact that people had been educated up to very pale lubricant oils. That was a practical suggestion of considerable value. The question of "gumming" was closely associated with it, and he assumed that the authors regarded "gumming" as specifically due to the more reactive of the unsaturated hydrocarbons. The speaker would ask this question: If the "gumming" were due to the probable oxidation or polymerization of the more reactive hydrocarbons present, would not restrained action of sulphuric acid, such as would be obtained by using acid of suitable dilution, possibly serve to remove the highly reactive hydrocarbons, whilst preserving the more stable ones, on the presence of which the authors consider the lubricating value to be so largely dependent?

Mr. E. L. Lomax thought the authors deserved the thanks of

the meeting for the manner in which they had marshalled such an interesting series of results obtained by different workers on a most important branch of petroleum technology. It was one eminently adapted to theorising rather than actual analysis, for the compounds concerned were so inert and difficult of separation and identification; and yet no product of petroleum had been more subjected to "additive synthesis" than had lubricating oil, with the numerous blendings which had been made to attain the elusive property known as body, oiliness or lubricating power.

Refiners would agree that viscosity in its wider sense was a constitutive property, but to what extent it depended on one particular type, or series of types, was an open question, and he would put forward the view that the lubricating value of an oil was influenced by both the unsaturated and saturated hydrocarbons present, whatever their chemical constitution.

He had, some time ago, an opportunity of treating some samples of lubricating oil by the "Edeleanu" process. As was well known, liquid SO_2 had the property at low temperatures of dissolving unsaturated hydrocarbons to a much greater extent than the saturated ones. Using that method, therefore, it was possible to extract the unsaturated hydrocarbons from a lubricating oil in a fair degree of purity, or at least containing only a very small percentage of saturated hydrocarbons. These unsaturated extracts could then be freed from SO_2, and the bodies obtained in a free state, which were formerly dissolved in the lubricating oil. If the view put forward by the authors were correct, one would expect that these extracted unsaturated hydrocarbons would possess ideal properties as lubricants.

At the lower temperatures, such as 20° C., the viscosity was undoubtedly very high, but the fall in viscosity on raising the temperature was so great that one could not consider them such efficient lubricants as the original oil from which they were extracted. On the other hand, the residual oil, after extracting these unsaturated bodies, had a much lower viscosity at the lower temperatures, but on raising the temperature the percentage fall in viscosity was much less marked, and yet at the same time this latter oil, containing a higher proportion of saturated hydrocarbons, could not be considered so good a lubricant as the original oil. This residue from extraction conformed closely to the acid-treated oils mentioned by the authors; as, by their method, only the more reactive unsaturated hydrocarbons would be extracted, and their product would still react with a further proportion of sulphuric acid, the resulting product giving other viscosity figures.

EXTRACTION OF LUBRICATING OIL BY LIQUID SO_2.

	Original Oil.	Refined Product.	Extract.
Specific Gravity	0·9165	0·903	0·9975
Viscosity at 70° Fahr.	240–241 secs.	167–170 secs.	360–364 secs.
Viscosity at 140° „	55–56 secs.	51–52 secs.	59–58 secs.
Specific Gravity	0·9165	0·888	1·024
Visc. at (21° C.) 70° F.	240–241 secs.	162–161 secs.	1580 secs.
Visc. at (60° C.) 140° F.	55–56 secs.	50–51 secs.	100 secs.

The drop in viscosity as between 70° F. and 140° F. was much more marked in the unsaturated portion than either in the original oil or in the portion containing a large percentage of saturated hydrocarbon.

It was asking too much to seek perfection in a lubricant, but a great deal might be done to discover the relative proportions of saturated and unsaturated hydrocarbons that would make the best lubricant for any particular purpose. If that could be discovered, progress would have been made towards a solution of the problem from a practical standpoint. In that connection, it was interesting to note the large proportion of unsaturated hydrocarbons present in Scotch lubricating oils, as shown by the iodine value. Those oils could not generally be classed as such good lubricants as either American or Russian oils. It was therefore possible that an excess of unsaturated bodies might decrease the lubricating value as well as a shortage of unsaturated bodies.

In conclusion, he would ask the authors whether it would be possible to amplify the tables of temperature coefficient by further figures as to the specific gravity, viscosity (Redwood), flashpoints, and tar values (Kissling method) of the oils employed, so as to enable the practical man to compare the new values with his constants of known value.

Mr. J. Wearham thought that the hexagonal figures which Dr. Dunstan had drawn on the blackboard illustrated a possible explanation as to the alteration in viscosity of oils under certain conditions. He thought, moreover, that if the molecules themselves changed, the relative position of the atoms or electrons would be altered. In each case the properties of the substances might be varied, and that suggested to the speaker a distinct field of research, namely, analysis and investigation of the constitution of oils under pressure as distinguished from those not under pressure. If the molecules were distorted, the relative positions of the atoms or electrons must of necessity be altered, and in each case isomeric compounds might result, which might explain the discrepancy

between the viscosity and the film factor in an oil. On a bearing it might be under tremendous pressure from the fly-wheel, and its constitution might be entirely modified. The lubricant might or might not be a good one, but, an alteration taking place in the molecules, and the relative positions of the atoms or electrons varying accordingly, the lubricant might become an ideal one. The speaker would regard it as interesting if some method could be devised of arriving at a constitutional formula for an oil under pressure; there might be a great difference when the oil was not under pressure. But even if the authors' suggestion did not hold, and the molecules were not actually in contact one with the other, but in a state of vibration, distortion of relative atoms might take place, for in this case the molecules would be held in position by certain forces, in certain directions, and increase of pressure on the outside would affect the lines of force between each individual molecule; that would react on the relative positions of the atoms. This might explain why certain oils, which appeared from the viscosity test to be poor lubricants, might, under the pressure of a heavy fly-wheel, have the constitution of its atoms or electrons so altered as to make it an ideal lubricant.

Mr. W. J. A. Butterfield remarked that engineers and physicists the world over, as well as the members of that Institution, would thank the authors for their contribution. He made that observation advisedly, because there had just come into his hands a reprint by Mr. C. V. Boys' Presidential Address to the Physical Society, delivered in January last, which referred to the property of "oiliness," and would show how greatly physicists would welcome this contribution by chemists to an elucidation of the matter. He would quote from the address as follows:—"When the worm gear designed by Lanchester was tested for efficiency at the National Physical Laboratory in that beautiful testing machine invented and designed by Lanchester also, a machine which directly measures the loss, instead of leaving it to be found as the small difference between two imperfectly-known large quantities, it was found that the lubricating property of oil depended on something which at present is unknown. It is not viscosity. Animal and vegetable oils lubricate better—i.e. they are more slippery than mineral oils of the same viscosity—and though the oil trade has known how to make good slippery mixtures, no one at present knows what 'oiliness' is, and this is at the present time an important physical quest of the engineer." In the authors' paper was a great deal that would help the physicists, and he hoped the former would find time to extend their investigations to solid bitumens and asphalts, with

a view to determining on what their viscosity or consistency depended. Reference had been made to the colloidal graphite used in oil-dag, and the speaker wondered whether an analogous part was played by the free carbon of tars or the finely-divided limestone dust of natural asphalts in regard to the consistency and physical properties of such materials. Another point was that with tars and tar oils, the solution in them of naphthalene had been shown first by American observers to diminish their viscosity considerably. That rather supported the work of the authors, because naphthalene was the antithesis of a colloid.

Mr. W. H. Howe wished to add a word of praise to that already given to the authors. The paper touched a point on which users of lubricating oil had long been waiting to obtain information. No doubt there had so far been a great chasm between the chemist and the user of lubricating oil, perhaps because the chemical tests had been beyond the pale of the ordinary mechanician. The engineer was a man of enquiring mind, and endeavoured to deal, as far as he was able, with the tests as offered, which confined him to the realms of theory. Speaking from the practical side of the subject, the tests had not hitherto gone far enough for the average user to understand how to apply them under given conditions. The paper, however, went a long way in solution of the problem of useful oils; for instance, on the point of surface-tension a further step had been taken towards securing a test that, in conjunction with standardised viscosity, would enable an opinion to be formed as to suitability. If the chemists would only apply their great knowledge more and more to the practical aspect of the matter, good results would follow. The outcome would be, in the speaker's opinion, that a large number of the lubricants at present on the market would either be dispensed with in regard to lubricating purposes as being but moderately satisfactory, or would be utilised in other directions. It would, he thought, be possible to define many of the qualities of oil now existing into certain standards, only suitable for certain purposes, which engineers would recognise, and so make sure of using good qualities.

It was a common mistake with ordinary individuals to mix up specific gravity with viscosity, heaviness in weight being confused, in their minds, with heaviness in body, or viscosity. He would ask the chemists whether there was any relation whatever between specific gravity and viscosity. He asked this, having in mind a peculiarity existing as between certain cylinder oils and spindle oils. In the case of one well-known cylinder oil of sp. gr. 0·896, the relative viscosity test gave 103·1, while in the case of a spindle oil

of sp. gr. 0·906, it gave 60·5. The assumption might be that the spindle oil, being heavier in weight, would have a heavier body, but actually the cylinder oil was lighter in weight, though showing greater viscosity.

Dr. A. E. Dunstan then replied to the discussion. Referring to the Chairman's interesting remarks about sperm oil, he regretted that for the present his attention and that of his colleague had been confined almost specifically to mineral lubricating oils, no measurement having been conducted with the animal or vegetable oils. He might point out that sperm oil was a somewhat unique material. In place of being a triglyceride, it was an ester of a monohydric alcohol, and an acid of the oleic series. It was of moderately high molecular weight, and had a somewhat high iodine value. It was characterised more particularly by the way in which its viscosity held up with increasing temperature. The speaker had on his notes a curve showing the viscosity temperature of a sperm oil and an American spindle oil. The spindle oil started at 60° F. had an absolute viscosity of 0·45; ultimately, at 212° F., this became 0·38°. The sperm oil (Archbutt and Deeley) had a lower viscosity, 42 at 60° F., but the curve soon crossed that of the spindle oil, and ended up, at the same final temperature, with 0·46. The two curves, plotted on the same squared paper, were not materially different, but they showed in the case of the sperm oil the very slow drop in viscosity with increasing temperature. He frankly confessed his ignorance of the cause of that result. Sperm oil was eminently unsaturated, and possessed body to a marked extent, with a very low temperature coefficient in viscosity. In future research he and his colleague intended to take into their purview some of the more important vegetable and animal oils.

Mr. Anfilogoff's letter more or less fitted in with the views put forward in the paper, but account could not be taken of one factor only, whether viscosity, surface-tension, possible colloid structure, molecular weight, or iodine value; the whole of the characteristics, chemical and physical, must be taken and considered together: there was no one criterion, nor any likelihood of such. We must make a clear distinction between the unsaturated hydrocarbons of high viscosity, normally present in lubricating oil, and the small amount of mobile volatile olefines resulting from almost unavoidable cracking during distillation.

Prof. Brame had touched upon a subject of extreme interest in his remarks on hysteresis; it was the hysteresis effect that had led the authors to the opinion that colloidal conditions were

undoubtedly present. The "network" theory had been brought forward and fully discussed by Glazebrook and colleagues in this Journal[17]. Holde's experiments would seem to show that "gumming" is not specifically due to the most reactive hydrocarbons (though the oxidation and polymerization of these may be partially responsible), but to the gradual concentration of the oxygenated compounds in the oil. When these were removed, a practically non-gumming oil was obtained. With the Prof.'s views on the minimum amount of acid, i.e. restrained treatment, his own perfectly coincided.

The authors were also in agreement with Mr. Lomax's suggestion that a better lubricating oil was obtained with the normal mixture—the partly saturated and partly unsaturated oil. Although the unsaturated compounds possess the higher viscosity and the higher body, yet in actual working conditions the presence of a diluent was an advantage. The fall in viscosity, illustrated by Mr. Lomax's figures, of the unsaturated components was very high. Undoubtedly in the lubricating oil synthetised by Krämer and Spilker there would be a correspondingly high fall. The point of view might, perhaps, be taken that the unsaturated hydrocarbons were the viscosity carriers in a saturated medium.

With regard to the Edeleanu method of separating the unsaturated hydrocarbons, compared with the sulphuric acid methods used by the authors, it was not, of course, certain that the sulphur dioxide had precisely the same effect; it would, for example, extract aromatic hydrocarbons, while it was possible that the sulphuric acid would not. It had been shown (*Allg. Ges. Chem. Ind. Berlin*, Ger. Patent, 287,309. 1913) that liquid sulphur dioxide removes the resinous components of a lubricating oil, but does not affect the unsaturated polycyclic hydrocarbons. As he had said, in the case of any particular oil, account had to be taken of the whole physical and chemical properties, and not merely viscosity, or specific gravity, or molecular weight, or surface-tension: to mention an extreme case, the viscosity of petrol fell off much less rapidly with temperature than that of any lubricating oil. Further data as to the oils worked with would be added to the paper.

An interesting suggestion had been made as to the effect of high pressure on molecules in general and oil molecules in particular. It might, in that connection, interest Mr. Wearham to know that the rate of shear, i.e. the speed at which the molecules were sheared one over the other, had a very great effect on viscosity. The speaker possessed a paper by Humphrey and Hatschek in which this question of the rate of shear was mentioned, the deduction

being that an increase in the pace at which the molecules passed over one another would diminish viscosity. The compressibility of liquids, water, for example, had been worked out by Tammann, who had also investigated change of viscosity under high pressure, with results which were probably of the first order.

In reply to Mr. Butterfield, he would say that until much more work had been carried out, "oiliness" would be, as Prof. Boys suggested, an absolutely unknown property. It might be, and probably was, the sum total of a number of effects; no one particular quality would give it. Richardson had demonstrated that the physical properties of asphalt paving were due to the colloidal nature of the clay and dust present. The speaker had not had an opportunity of investigating the viscosity of bitumens at all. As to the point that naphthalene reduced the viscosity of a tar or mineral oil, that also was of great interest. Probably Mr. Butterfield was familiar with the case of ethyl alcohol, in which dissolved naphthalene sent down the viscosity. He had met with several cases in which viscosity curves, of say liquid A or liquid B, benzaldehyde and alcohol, showed a similar large depression. That had been explained by the fact that adding the aldehyde to the alcohol had the effect of breaking down the complexes known to exist in ordinary alcohol. Apropos of that, he would take the case of ordinary gelatine jelly, which illustrated the hysteresis effect of oils most admirably. The addition of $\frac{1}{2}$ % of potassium thiocyanate prevents gelatinisation.

As to the connection between viscosity and specific gravity, the higher the specific gravity in distillates from a given crude oil, the higher would be the viscosity, but such parallelism would not hold between oils of different origin. In the case cited, the cylinder and spindle oils were clearly of widely different origin and chemical nature.

The Chairman then proposed a vote of thanks to the authors, remarking that Dr. Thole would not be jealous if he, the speaker, commented on the lucid manner in which Dr. Dunstan had replied to the questions raised.

Subsequently **Mr. E. A. Evans** wrote as follows:—Although lubrication experts have discussed the terms "body" and "oiliness" assiduously, one is a little disappointed at the scanty literature on the subject. It has long been assumed that surface-tension has an important bearing upon the subject. No doubt it has, but what I fear might result if this were recognised is that people would demand it as a standard for lubricants, just as some people still pin their faith to the lubricating value of an oil as

determined by an oil-testing machine. Surface-tension might be included in a specification with perhaps some advantage, but not until we understand thoroughly its significance. Chemists must avoid filling the engineer with glee at the probable introduction of a new standard by which he can judge his lubricants, until the new standard has stood the test of actual practice. Personally, I doubt whether a universal standard of any kind can ever be adopted, because of the extremely different conditions met in practice. Theoretically, of course, the ideal lubricant is one which will reduce friction to a minimum—in other words, is one which has a good lubricating value—but we know only too well that the lubricating value has at times to be sacrificed to some extent for stability and other characteristics. Hence we judge an oil not on its lubricating value alone, but on its value as a lubricant.

In future publications I hope that elastic expressions such as "spindle oil," "engine oil," "cylinder oil," etc., will be supplemented by sufficient detail to render the oil recognisable.

Irvine, in the Annual Report published by the Chemical Society for 1915, says: "Substances which are in universal and urgent demand are unlikely to be the subject of detailed examination so long as attention is, for the time being, focussed on their economical production and use. It is therefore not surprising to find . . . that the simpler hydrocarbons have been studied by the engineer rather than by the chemist, and that the pages of scientific journals contain few references to these compounds."

I think Irvine's words must be modified to meet the conditions of to-day.

It will be of interest to give some published results of surface-tension of some oils as determined by Proctor Hall's method:—

Oil.	Surface-tension.	Oil.	Surface-tension.
Scotch 880/885	39·34	American 865 pale neutral ..	39·55
Russian 895	42·03	,, 912/915 pale ..	43·26
,, 907	43·55	Stettin colza oil	47·60
Arctic sperm oil	44·03	Castor oil firsts	54·72

Upon which **Dr. Dunstan** rejoins thus:—

The figures quoted by Mr. Evans for the surface-tension of various oils are of great interest. Qualitatively they seem to fit in with the other constants of the oils. We quite agree that the time is not yet ripe for basing any general conclusion on surface-tension values. On the other hand, we wish to emphasise the extreme importance of the correlation of all the physical properties with the, as yet, unsolved chemical nature of oil.

Thirty-First General Meeting.

This Meeting was held at the House of the Royal Society of Arts, on Tuesday, 28th May, 1918, Sir Boverton Redwood, Bart. (Vice-President), occupying the Chair.

The Members of Council present were Messrs. H. Barringer, Andrew Campbell, E. H. Cunningham Craig, Arthur W. Eastlake, and T. C. Palmer.

The Hon. Secretary (Mr. Arthur W. Eastlake) announced that the following gentlemen had been elected:—

As Members:—George Howard Coxon, John Gillespie, Thomas Pearce, Edward Patrick Reilly, Leslie Urquhart, and Roland Wallis. As Associate Member:—John Arthur Greene. As Associate:—Charles Edward Best.

The Chairman announced that, greatly to his disappointment, the President, who had hoped to take the Chair that evening, at the last Meeting of the Session, was precluded, under doctor's orders, from incurring that exertion, although the members would be pleased to hear that Mr. Greenway had made a remarkably satisfactory recovery from his operation, and had already spent some hours in attending to urgent matters of business. The Honorary Secretary, Mr. Eastlake, had received a letter from him in which he said that he was sorry the doctors stated that he must avoid anything in the nature of continuous or protracted work for some little time longer, and, although he had been to his office, he had, under medical orders, returned to the country for a short time.

The paper which was to be read was by Mr. Wilfred Burford, and he had, on behalf of the author, to express his regret that some thousands of miles of ocean separated him from the members at the present time, and that it was impossible for him to be present in person to read the paper. The Council, however, had been able to induce Mr. E. G. Holiday, who had conferred a similar service upon the Institution on a former occasion, to take the author's place, and, having regard to the manner in which Mr. Holiday acquitted himself on that previous occasion, he had no doubt whatever that he would do full justice to the views of the author in the presentation of the paper.

The Application of Electrical Power to Oilfield Requirements.

By J. Wilfred Burford, M.Inst.M.E., A.M.I.E.E., *Member*.

Introduction.—In submitting this paper to the Institution of Petroleum Technologists, the author has two objects in view:

First, to endeavour to point out, to people responsible for the efficient working of oilfields, the great economies and advantages to be gained by the judicious installation and careful maintenance of electrical machinery, in place of the notoriously inefficient steam-plant at present so much in use on the majority of oilfields throughout the world, and of the indiscriminate installation of gas- and oil-engines for power-purposes. Second, to point out to the large number of manufacturers of electrical machinery in this country, the extensive field they have at their disposal on these oilfields for marketing their goods, if they will carefully study the requirements of the petroleum-producing industry.

That this market really exists will readily be understood, when one realises the magnitude of the industry in the United States of America, Russia, Mexico, Galicia, Rumania, the Dutch East Indies, India, Japan, Peru, and the Argentine Republic. Furthermore, prospecting work is continually being carried out in many other countries, and fresh fields developed.

Speaking generally, it is safe to say that fully 60 % of the power-requirements of the oilfields in these countries are provided for by wasteful steam-plants, 35 % by gas- and oil-engines, and not more than 5 % by electric motors. That only 5 % of the total power-requirements of the industry have been met by the use of electricity, would, at first sight, appear an argument deprecative of its use. It must be borne in mind, however, that this is an average for the whole industry, and that it will be higher for some countries and lower for others. In districts where this form of motive power has once obtained a footing, and has not been confronted by an abnormal amount of prejudice (as, for instance, in Russia and Rumania), it has quickly proved its efficacy. As bearing out this statement, the figures given by Mr. Rappoport, in his paper before this Institution on March 18th, 1915, "The Internal Combustion Engine on the Oilfield," showing the increase of the use of electric motors on the Baku field of Russia, are very enlightening. These are as follows:

Year	1910	1911	1912	1913
Total number of wells	3,001	2,964	3,422	3,670
Total number of wells worked electrically	361	440	657	1,002
Percentage of total	12	15	19	27

From the above figures it will be seen that the number of wells on these fields using electric motors had almost trebled in three years. The increase from 657 wells in 1912, to 1,002 wells in 1913, is indeed a significant fact.

Many people holding responsible positions in connection with oil undertakings will still bring out the well-worn expression that "electricity is still in its infancy" (a very highly developed infant!), and that its use is too uncertain and undeveloped to warrant its advantages being considered, little realising how much our large cities and towns depend upon it to-day for their very existence.

This form of power is now being employed for handling many of the most exacting demands in the engineering industry, such as, for instance, the driving of rolling mills, crane work, main and tail haulage in mines, and heavy traction work; in all of which it has proved eminently successful.

It will, perhaps, not be out of place at this point to say that electricity was a large factor in saving the nation at a very critical period of the war, as the public plants throughout the country were almost the only sources of power-supply ready to meet the large demands for power for the manufacture of munitions, when it was realised how necessary these were to carry the war to a successful termination.

It is not, of course, intended to convey the idea that electricity is the key to success in all instances; but neither does it follow that because it has not been a success in one place, it will fail in another. Local conditions must be carefully studied in all cases, and every factor taken into consideration. Fields situated on the shores of the Caspian Sea, and fields such as those of Peru, where good water for boiler-feed purposes does not exist, and where the crude oil used for fuel for steam raising purposes is of a high grade, and worth probably £3 per ton, will show much superior results for electrical working than will fields where the oil used for fuel is of poor quality, and not worth treating to recover the lighter products, and where good boiler-feed water is available close to the well-sites, as is often the case, for instance, in the Mexican fields.

Another factor showing the advantage of electric drive, is that of reliability from breakdown, and greatly decreased cost of repairs. Here, again, local conditions must be studied. It will be readily understood that repairs for any class of machinery will be far less, and cheaper in West Virginia or California, where large numbers of expert mechanics and reliable machinery-attendants are always available, than they will be on the fields in the Peruvian desert, where one has to rely upon ignorant natives to watch a large amount of the machinery, and depend upon expensive and far from capable mechanics to carry out repair work. Furthermore, spare parts to carry out these repairs have to pay heavy freight charges and

Custom House dues before they reach their destination. It is therefore advisable, in order to avoid these expenses and the employment of costly and inefficient labour, to install the most reliable class of machinery procurable on fields far removed from the supplying establishments.

That modern electrical machinery is far less complicated and infinitely more reliable and efficient than steam-plant, will not be denied by any engineer who thoroughly understands the principles of the two forms of power; and when comparing electrical machinery with the majority of steam-plants in use on oilfields, there can be no question as to which is the more desirable. In many steam-plants used for oilwell drilling, the thermal efficiency will be no higher than 4 %, whereas with power generated by internal-combustion engines using natural gas, the brake thermal efficiency may be as high as 30 %, and this, by utilising the heat of the exhaust gases, may be raised another 10 %. In the case of Diesel or semi-Diesel oil-engines being used as prime movers, the thermal efficiency should be as high as 40 %, which could be raised to 50 %, by utilising the heat from the exhaust in suitably-arranged steam-boilers.

Another advantage gained by this centralisation of power-generation is that of being able to bring all the natural gas on the field to one point, and there treat it for the extraction of its condensable vapours before passing it to the main engines, the resulting gasoline being a very valuable by-product at the present day.

In cases where electricity has not proved a success on oilfields, due to the motors "stalling," and to transmission-lines breaking down, the failures can be traced to faultily-designed installations and the prejudice of ignorant operators.

Before erecting machinery to carry out certain work, it is essential that all particulars of the work and of the demands to be put upon the machinery should be carefully ascertained, and a factor of safety allowed. In early applications of electrical power to oilfield requirements this essential does not appear to have been realised, with the result that installations were much underpowered, and provided with inadequate protective gear.

Modern electrical machinery has been brought to a point of perfection as regards immunity from breakdown and in simplicity of operation. It is now usual for manufacturers to advertise their appliances as "fool-proof." Its suitability for minimising fire risk to the lowest point possible is borne out by the fact that large numbers of motors have been installed in positions where risk from

fire is pronounced, such, for instance, as in distillate pump-houses and in coal mines, because of the element of safety attained by their introduction.

Two of the reasons for the non-introduction of more economical forms of working on oilfields, have been the old cry of many operators that "a big production beats small economies," and the "laissez-faire" attitude of some directors and managers. As regards the first of these, the one idea of people with the big-production craze is to get oil in the largest quantities possible, in the shortest space of time, irrespective of the cost of production and the demands of the market, as long as a reasonable profit is being made. The second case is somewhat similar: as long as a good profit is being made and dividends paid, the shareholders are happy, therefore there is no call to spend more money in extra plant. It is, however, possible to introduce more economical methods of production without curtailing the amount of oil produced: on the contrary, improved methods always tend to increase production besides cheapening it, so that a double and very satisfactory object is gained.

In many instances, the oil industry to-day is in much the same position as were the coal and engineering industries twenty years ago. At that time electricity was struggling to get a foothold in these industries to replace the appallingly wasteful steam-plants in use. That this term is not too pronounced, none will deny who visited many collieries at that time, and some of the large engineering works on the Tyne and Clyde. It was quite usual for a colliery to consume 10 % to 12 % of its output, which figure, by the introduction of electric power from centralised plants, has been reduced to 3 %. In the Baku oilfields, the percentage of oil used for fuel to the total produced has risen to the very high figure of 15 %, according to figures given by Mr. Rappoport, the value of this oil being £2,600,000 in 1913. In another field, producing about 6,000 tons of very high-grade oil per month, it is not unusual to consume 250 tons per month for fuel. This represents over 4 % of the total production, although large quantities of natural gas are also consumed. Assuming a value of £3 per ton, we arrive at the conclusion that £9,000 per annum might be saved on this item alone. These figures give much food for serious thought, especially when it is realised that crude oil will, without doubt, rise to a very high value in the near future.

Electrical power is extensively used for drilling, cleaning out, and pumping oilwells in the United States of America, especially in California and West Virginia. In California power is supplied

by large hydro-electric power-plants, such as the Pacific Light and Power Co. and the San Joaquin Light and Power Co. In the latter case, power is generated and used by the South Penn Oil Co. from a power plant operated by large gas-engine units.

For supplying power to the oilfields of Rumania, two power-stations are established, one using water-power, and the other steam-plant.

Power in the Baku district of Russia is also furnished from two power-houses, aggregating 20,000 horse-power.

The power requirements of oilfields constitute: (*a*) The actual drilling of the well, by either the cable system, pole-tool system, or by the rotary method. (*b*) The production of oil from the well by independent pumping, group pumping, bailing, and swabbing. (*c*) The repair of producing wells, consisting of pulling pump rods and tubing, redrilling and cleaning out cavings. (*d*) General power requirements, such as pumping oil and water-supplies on the surface for field consumption and to storage; machine shop, carpenter's shop, smith's shop, and boiler shop driving; electric lighting, etc., etc.

Cable Tool Drilling.—In this system of drilling, power is imparted from the engine to a 10′, 11′, or 12′ diameter bandwheel. This bandwheel provides the motion, through the medium of a crank and "wrist pin" on one end of its shaft, for raising and dropping the drilling tools during drilling operations. On the opposite end of the shaft is a chain-sprocket wheel, connected by chain, through a clutch, to the "calf wheel" which is used for working the casing for lining the well. Bolted to one side of the bandwheel is a double grooved tug wheel 7′ 6″ in diameter, used for driving, by ropes, the "bull wheels," on the shaft of which is spooled the drilling line for suspending the drilling tools. Behind the bandwheel, and worked from it by a 40″ friction pulley, is the sandreel on which is spooled the steel sandline, used for bailing detritus from the well.

The great complaint against the use of electric motors for oilwell drilling, has been their supposed lack of flexibility as regards speed regulation, and the inertia of their revolving parts, the latter characteristic preventing a free drop of the drilling tools, which is very necessary for obtaining the best results. A wide range of speed and fine regulation is essential, especially when drilling with a manila cable, as the motion of the "walking beam," from which the drilling tools are suspended, must synchronise with the natural period of vibration of the drilling line, otherwise dangerous strains will be put upon the line and the rig. This great essential when using the manila line is not so pronounced when a wire line

is substituted, owing to the latter's lack of elasticity, the decreased length of stroke, and increased speed of the motion. At the top of the hole, when commencing the well, the number of blows may be as high as 60 per minute, decreasing to 25 at a depth of from 1,200′ to 1,600′, if a manila line is retained to that depth. It must be borne in mind, however, that in drilling with electric motors it is usual to discard the manila line at from 400′ to 500′, and replace it by a wire line. In this case the speed would be higher than 25 blows per minute at considerably greater depths. Fine speed-regulation should be provided between 30 to 50 revolutions of the bandwheel, while from 25 to 30, and from 50 to 60, the regulation need not be so close. A top-speed of about 65 revolutions should be provided for, also a very slow or creeping speed for handling some fishing operations. That modern electric motors eminently comply with all these demands will be clearly shown in a later section of this paper.

The power taken in actual drilling operations, i.e. in raising the tools for the successive blows, will average from 15 to 25 horse-power, according to the depth and diameter of the well, and the length of stroke. The stroke may vary from 2′ 6″ to 5′. In starting the well a short stroke and high speed prevails, while as the well deepens, the stroke is lengthened, and the speed diminished. The time taken to "run out a screw" may be anything from half an hour to three hours. The power taken will vary from 0 to a maximum of 25 hp. every stroke of the tools. When the "screw" has been run out, power is shut off while the driller disconnects the drilling motion preparatory to drawing the tools from the well. To draw the tools from an 8″ hole to an average speed of about 250′ per minute, will require roughly from 30 to 35 hp., which would require to be applied for ten minutes for a 2,500′ hole, when power would again be shut off. The next operation is to bail the detritus from the well, which usually necessitates the bailer being run three or four times. Drawing the bailer from the well will require from 25 to 30 hp., and will have to be applied for about five minutes each run for a hole of this depth.

The power required for casing operations at the well will vary considerably, and these operations will entail the hardest duty which the motor will have to perform. For this work a very flexible form of power is required, as the load may fluctuate between nil and 100 hp., or even more, in the shortest space of time, with frequent reversals. Furthermore, it is very essential that high torque should be possible at slow speeds, especially when casing has become "lodgy." This characteristic is common to electric

motors, and makes them eminently desirable for this work, and it is in direct contrast to oil- or gas-engines for drilling, as with these engines their torque is directly proportional to their speed. The fault (if so it can be called) of the electric motor, is its willingness to take more work than it should, due to its high overload capacity, and the consequent danger of either pulling in the derrick or parting the pipe in the well during heavy pulling operations. This danger, however, can be entirely obviated by careful handling, and by having a suitably calibrated instrument in view of the driller, showing exactly what pull he has on the pipe.

In some instances a water-flush is used in conjunction with cable tools for overcoming high gas pressures. In this case a power-driven pump, taking from 15 to 20 hp., will be necessary, and should be driven by an independent motor.

Pole Tool System.—This system of drilling differs considerably from the cable tool system, inasmuch as iron rods $\frac{7}{8}$″ or 1″ diameter by 40′ in length are used for raising and lowering the drilling tools in the borehole. The running gear also differs widely from that used in the cable system. The walking-beam is much shorter and heavier, and the motion more rapid; the speed of the beam being as high as 80 strokes per minute at the top of the hole, and the length of the stroke from 12″ to 24″.

Power is transmitted from the drilling engine to a 6′ 6″ band-wheel on a countershaft, which also carries two other pulleys and a crank. These two pulleys are for driving a sandline spool for working the bailer, and a draw-spool which is used for drawing the drill poles from the well, and also for working the casing through the medium of heavy 4 or 6 sheave-blocks. The belts from the pulleys on these spools hang loosely down and around the two pulleys on the countershaft, and are actuated by "jockey-pulley" belt-tighteners.

The power required to work this system of drilling is very slightly in excess of that for the cable system. The bailer is worked by a $\frac{3}{4}$″ sandline, and has a set of light jars attached. In pulling the tools from the hole, each 40′ length of drill-pole has to be disconnected, and stood up in the derrick. For this operation the driller "races" the engine by means of a "lightning valve," worked by a foot-pedal, and then pulls over the belt-tightener, causing the tools to be drawn up 40′ at high speed. The time taken to pull each rod length will be about 10 seconds, with 15-second spells of "no load" between each pull. The work will require about 30 hp. for 10-second periods until the tools are withdrawn from the well. Bailing will require about 35 hp., and drilling about 30 hp.

In drilling by this system the cause for complaint against the electric motor of non-flexibility and inertia of its revolving parts almost entirely disappears, for but little difference in speed can be noticed between dropping and picking up the tools. This is of course accounted for by the rigidity of the drill poles, the short stroke and quick motion, this system not necessitating the fine speed-regulation called for by the cable system.

The power required for casing operations will be heavy and intermittent, and similar to that with the cable-tool system, with the exception that it will not be necessary to reverse the motion of the motor.

Rotary System.—Rotary drilling would appear to present by far the most suitable conditions for the application of electric motor drive. The power for rotating the drill stem represents a steady load for considerable periods; as also does that taken by the mud-pumps; and very exacting speed-regulation is not called for. The economies in fuel and labour that will result will be very pronounced, since it is usual with this system to employ two steam-boilers of 40 hp., owing to the great amount of steam taken by the mud-pumps. A power-driven mud-pump will require a 15–20 hp. electric motor, while power for drilling the well should not average more than about 25 hp. The two steam-boilers would without doubt consume from two to three tons of oil-fuel per day, and require the attention of two firemen. By using electric motors, the expense of the firemen would be entirely eliminated, and the fuel-cost would be very greatly reduced. According to the latest information, the deepest well drilled by this system using the electric drive is 1,500′. Three shallow wells were successfully drilled thus in California in 1914 and 1915 by a contractor, being the first application of electricity to this system of drilling. At the present time the General Petroleum Co., at Taft, California, have in operation a 75 hp. electric rotary drilling equipment which has completed four or five wells successfully.

Production by Pumping.—When the conditions prevailing at a producing well necessitate its being worked by an independent form of power, for the purpose of pulling pump rods and tubing and occasional cleaning out, it has been common to leave the drilling rig and machinery in place, a very costly practice, or else to install a 25–30 hp. gas engine with reversing clutch, and a light form of rig and derrick. This duty can be carried out most efficiently by either single speed or two-speed electric motors (to be described later) at very much reduced cost, the low speed and low

power being used for pumping, while the high speed and power is utilised for pulling rods and tubing and cleaning out.

Group Pumping.—This method is used for pumping groups of wells of moderate and fairly permanent production. In general practice the groups will consist of from 6 to 18 wells. The wells are connected by "jerker lines" to a central pumping-power. These pumping powers are usually driven by standard-size gas-engines of from 20–30 hp. The larger size is preferable if the set has to run for 24 hours per day, and for 365 days per year, and if sea-water or other unsuitable water has to be used for cooling the jackets of the engines. Owing to the difference in manufacturers' ratings of gas-engines and electric motors, a 15 b.h.p. motor would take the place of the 30 hp. gas engine.

POWER REQUIRED FOR PUMPING 213 OILWELLS IN CALIFORNIA.

	Bbls. per Well per day.	Depth of Wells.	Kw. hrs. per Well per day.	Kw. hrs. per Bbl. pumped.
Max. ..	230	3,110	123·4	5·843
Min.	10	900	27·7	0·414
Average ..	122	1,430	80·8	0·683

Production by Bailing.—The power required for the trial bailing of a new well, by the bailer ordinarily used during drilling operations, or one slightly larger, will be somewhat more than that already mentioned for bailing the detritus from the well, as there will be a considerably greater depth of liquid in the hole, which will, of course, have to be displaced by the bailer as it rises to the surface.

The permanent production of oilwells in the Baku fields of Russia is carried out by bailing, using very large bailers, sometimes 12″ diameter and 60′ long. The bailers raise a great deal of sand and water with the oil. The speed of bailing is well over 1,000 feet per minute, and the power developed may be as high as 150 hp. As steam is supplied to the bailing engines at a pressure of about 60 lbs. per sq. in., through long pipelines, it will readily be understood how thoroughly uneconomical and wasteful the plant must be. Recently a good many gas- and oil-engines have been installed for bailing groups of fairly close wells, but in many cases, electric motors would show much superior results, owing to cheaper first cost, greater overload capacity, decreased cost of working and maintenance, lower depreciation, and adaptability to automatic control.

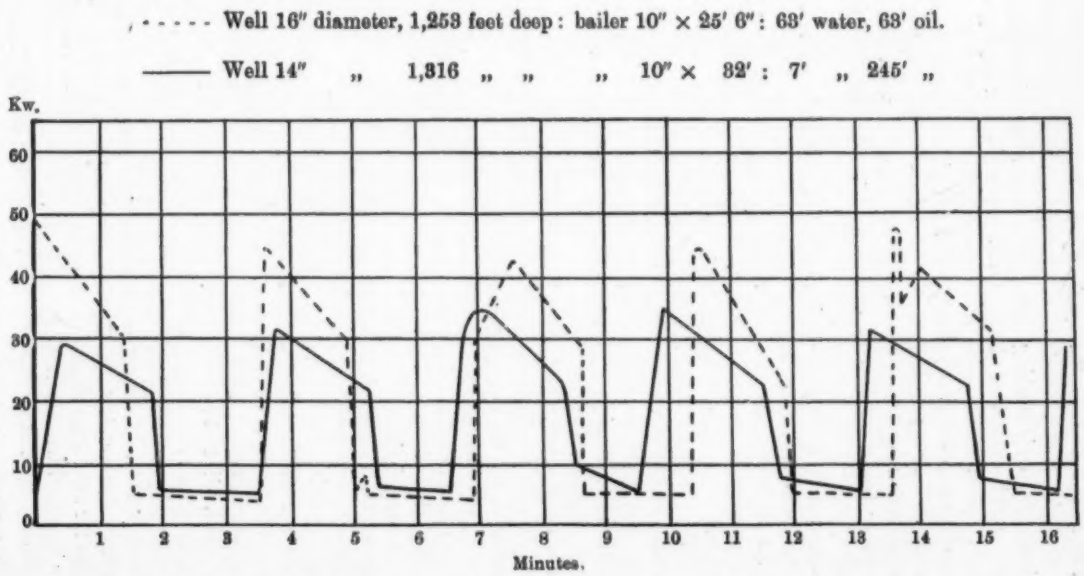

Fig. 13. Load Curves of Bailing Well.

The diagram fig. 13, taken from Mr. Beeby Thompson's "Oil Field Development," very clearly shows the character of the load at a bailing well, and also demonstrates a very great advantage obtained by electric working, namely, the ease with which accurate records can be obtained of the power expended to carrying out different operations.

The size of motor required for this work will of course depend upon many factors; such as depth and size of well, quantity of oil, sand and water to be raised, depth of liquid in well, and the probability that a number of wells will be worked together as a group.

Production by Swabbing.—This method of production is mostly used in the Boryslaw-Tustanowice oilfield of Galicia. The swabs used for this work are operated by double-cylinder direct-acting winding-engines of moderate power. These are locally known as "haspels." These machines are listed in sizes from 50 hp. to 200 hp. The latter size has cylinders about 14″ × 18″, and takes steam at a pressure of 140 lbs. per sq. in. As the swabs are often raised at a speed of 2,000 feet per minute, the character of the load is very intermittent, with high peaks, resulting, of course, in a very low overall efficiency.

The author much regrets that he is unable to give any actual figures showing the power used, and its cost, at wells producing by this method, but that the service is severe there can be no doubt, since the power-demand will rise from zero to a maximum of 200 hp. and drop to zero again within the space of two minutes, the cycle being repeated several times per hour at some wells. The capital cost and depreciation for winding plant of this description, including boilers and their auxiliaries, must be very high when compared with electrical winders which would handle the same work.

The theoretical load curve of a 200 hp. swabbing haspel, making ten winds in the hour, shown in fig. 14, gives a good idea of the nature of the load to be dealt with. A steam haspel of this power will cost about £350, while the steam plant (boilers, feed-pumps, tanks, etc.), will cost another £500. An electrical winder to handle this load would also cost about £350, including all control gear, and driven by a 80 hp. motor, having 130 % overload capacity for short periods. As many of the more important producing wells are fitted with duplicate plant, the capital expenditure and other charges for steam plant will be many times that of the electrical plant if several wells have to be equipped.

The cost of electrical power for the winder under discussion should not be more than 795 kw. hrs. per day of 24 hours, which,

with current at three farthings per kw. hr., amounts to £2 9s. 7d., whereas the steam-plant will require at least two tons of fuel-oil, which at £3 per ton works out at a cost of £6 for the 24 hours. To this must be added the cost of feed-water and general engine-room stores, increased cost of lubricating oil, higher cost of repairs, boiler-cleaning, fireman's wages, etc., etc.

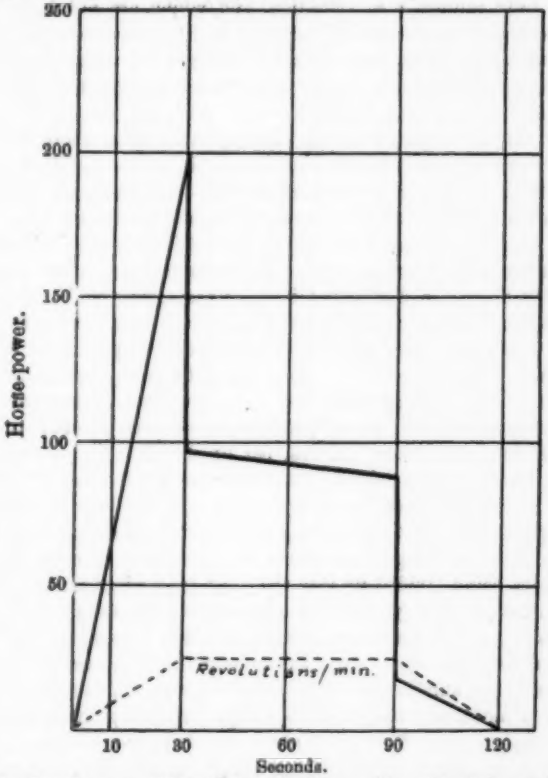

FIG. 14. Load curve of Swabbing Engine, making 10 winds per hour.

Repairing and Cleaning Wells.—The power required for these operations will be considerably less than that necessitated by the original drilling of the well, as no heavy strings of tools will have to be manipulated, and no heavy casing work undertaken.

As already stated, single-speed and two-speed alternating-current motors are used for this work. These motors are made in

two sizes: 8–25 hp. and 15–30 hp. The operations of pulling sucker rods and tubing entail severe service, and the power required may rise as high as 80 hp. for short periods. Such heavy loads are handled by these small motors by designing them with a 300 % overload capacity for very short periods.

For pulling tubing and rods at producing wells of moderate depth which only require rare attention, and which are not large producers, a portable hoist, driven by a 15 hp. motor, should prove equal to all requirements. This hoist should not weigh more than 1,400 lbs., and therefore could be easily moved about the field.

General Power Requirements.—The principal uses for which power will be required on an oilfield, other than those already mentioned, will be for pumping the main water-supply for the field, field oil-pumping stations, storage-tank pumping stations, and main pipeline and cargo-pumping requirements. For all these pumping operations, either gear-driven power pumps or centrifugal pumps can be used. If the pumping sets are of large capacity, there is no doubt that, in many cases, it would be advisable to install the latter type, either single or multi-stage, owing to their much lower first cost, and the small space occupied. As is well known, centrifugal pumps of large capacity are quite economical, whereas direct-acting compound steam-pumps will require from 60 lbs. to 125 lbs. of steam per hp. hr., and simple-effect steam-pumps from 100 lbs. to 250 lbs. per hp. hr.

For machine-shop driving, the electric motor is ideal for oilfield work, where it is often necessary to run only one or two machines throughout the night for making or repairing special fishing tools. If the shop is a large one, group-driving can be resorted to, the machines being divided up into the most convenient units, or even driven independently. Smith- and boiler-shops should be driven independently of the machine-shop, for the reason that if tool-dressers are required to work throughout the night, as is often the case, only one small motor need be run to supply air to the forges.

For a moderate-sized machine-shop, containing three lathes of varying sizes, from 6″ to 18″ centres, two drilling-machines, planer, shaping machine, two pipe-screwing machines, bolt-screwing machine and two emery-grinders, a 15 hp. motor should prove quite adequate. For the boiler- and smith's-shop, with a 7 cwt. pneumatic power-hammer, plate-rolls to work 10′ × $\frac{3}{8}$″ plates, and a punching and shearing machine to punch 1″ holes and cut 1″ plate, installed, with a 36″ blowing fan, a 15 hp. motor would be necessary. A motor of this size could handle the work satisfactorily, provided that no heavy forging and plate-rolling work had

to be carried out at the same time, a state of affairs which would be very exceptional. The carpenter's shop, containing circular saw, band-saw, and planing machine, should also be equipped with a 15 hp. motor.

An electric motor to replace the time-honoured, much-abused, and long-suffering steam drilling-engine, must be capable of carrying out all the operations that the engine has performed, and a good deal more, if it is to win the favour and confidence of present-day oilfield operators. It will have to do its work as reliably as, in fact more reliably than, the steam-engine, under equally unfavourable conditions.

Either multi-phase alternating-current, or direct-current motors are suitable for drilling. Some engineers labour under the delusion that electric motors, and alternating-current motors in particular, are unsuitable for drilling operations, owing to poor speed-regulation. To those who hold these views, the author would state that continuous current motors are made, which will develop full load torque from full speed to 30 % of full speed, or even lower, at maximum efficiency.

Alternating-current motors also lend themselves to good speed-regulation, and a very wide range can be obtained by the insertion of resistance in the rotor circuit, though at the expense of the efficiency of the motor. This characteristic, however, is of little importance, especially if power is being obtained from natural gas from wells on the property owned by the operating firm. Even if the motor should have to work for considerable periods at 50 % efficiency, obtaining its energy from oil-driven generators, the results would be infinitely better than those obtained by independent steam-plants. Specially-designed drilling equipments are planned to run at 50 % speed reduction continuously when exerting full-load torque, and will run at greater speed-reduction continuously if the load is lighter than this. A main resistance is provided in the secondary, which will reduce the motor speed to a standstill at 75 %, will run at ⅓rd speed at 50 %, and at ⅔rds speed at 25 %, of full-load torque. An auxiliary resistance, provided for fine speed-control, will give still lower speeds when cut into the circuit. Under certain conditions the starting torque of these motors can be 200 % of full-load torque, and under ordinary working conditions they have momentary overload capacities of 300 %. The following table, taken from "Standard Polyphase Apparatus and Systems" by Maurice A. Oudin, and the attached diagram (fig. 15) show clearly some of the characteristics of three-phase alternating-current motors :

Speed.	Efficiency.	Power Factor.
Full	88 %	0·86
Half	41·5 %	0·86
Quarter ..	21 %	0·86

These motors, for both drilling and special pumping operations, have now been developed by the General Electric Co. of America to a highly satisfactory degree.

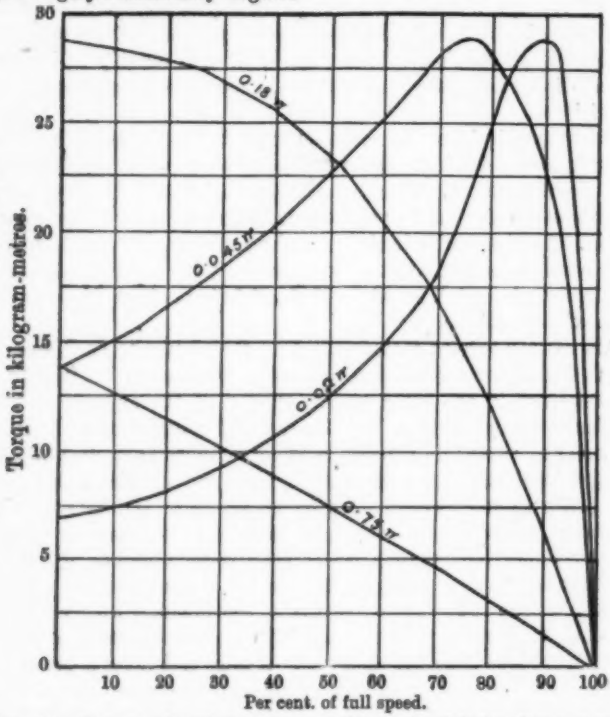

FIG. 15. Curves showing torque and speed of induction-motors, with varying rotor resistance. C. F. SMITH, Practical Alternating Currents.

Experience has shown, that for drilling, the most suitable motor is the standard variable-speed type, with wound rotor and slip rings, and rheostatic control. In the author's mind there is no doubt that the two-speed type of motor would show better efficiency for drilling work, just as it does at producing wells, since nearly all the operations requiring reduced speed take reduced

power; but, as the many operations at a drilling well follow so closely upon one another, and as the oilwell driller is frequently neither conscientious or painstaking, or even moderately trained from an engineer's point of view, and as he will frequently not be bothered to go to the motor to throw-over the pole-changing switch, but will be content to endeavour to carry out the heavy work with the motor running on the low-power side, it is preferable to have the standard type of motor, and sacrifice efficiency for the sake of simplicity and reliability.

On account of the heavy strains to which the equipment is subjected, the motor for drilling is used with a belted countershaft in preference to back gears. It is usual to install a motor of 50 b.h.p., for wells down to 2,500′ deep, while for wells of greater depth it is advisable to install a 75 b.h.p. motor. Both the main and auxiliary controllers are situated near the motor with their resistances, and are worked from the "headache" post by the usual wheels and telegraph cords, no reverse lever being required as with the steam engine. The motor is protected by a main oil-immersed switch, having no-voltage trips, and inverse time-limit overload trips.

For pumping, cleaning and repairing producing wells there are, as already mentioned, two types of motors. First the single-speed motor. This machine is equipped with a change-over switch mounted on the frame which will connect the stator windings, either Y or delta, giving the motor a difference in capacity as 1 to 3. The Y connection is used for pumping, and the delta for pulling rods and tubing. Excellent characteristics are obtained on either connection. On the two-speed machines, a switch is also mounted, which changes the poles of the motor, and its synchronous speed from 600 revolutions to 1,200 revolutions per minute, and its rated capacity is increased on the higher speed. Motor protection must be provided on both the high and low ratings, and this is obtained by the use of double-wound trip-coils, so interlocked with the pole-changing switch on the motor that the proper protection is automatically obtained for either connection of the motor.

The work of pulling out rods and tubing, as well as replacing them, requires that they be unjointed and handled in 20′ lengths, and this involves considerable manipulation of the motor with frequent reversals at high speed. The best results are obtained by making use of the high-torque capacity of the motor, the full benefit of which is obtained on the auxiliary controller-points. A number of equipments are now provided with a device which entirely relieves the operator of the necessity of keeping this matter in mind

on every reversal, as it automatically stops the controller at the most advantageous point, until the input has fallen to a value at which the remainder of the resistance is no longer necessary in circuit. The device also acts as a protection to the motor, as it lowers considerably the current input while reversing.

Pumping groups of wells from central pumping powers by "jerker lines" can be handled by ordinary short circuited rotor, or squirrel-cage motors, provided that starting is accomplished on a loose pulley.

Continuous current motors for either drilling, pumping or repairing oilwells, or for bailing or swabbing, should be compound-wound and fitted with interpoles. These latter will enable the motors to handle heavy overloads without sparking, while the series-winding will give the motor good characteristics for handling heavy casing operations. Shunt field-regulation, bringing the motor speed down to 25 % of full speed by about 40 suitably graduated steps, gives very good results for all drilling operations, and a series-control can be arranged for starting up and stopping and reversing the motor, and also for obtaining a creeping speed for fishing operations. The switchgear should be provided with no-volt, and inverse time-limit overload trip-coils. It should also be made quite "fool-proof," and the different elements interlocked, so as to afford complete safety to operators and motors.

Choice of System.—The system to be used—either polyphase alternating current, or continuous current—will depend largely upon the system of public supply, if such is available. The alternating-current system, however, has many advantages over the direct-current system for oilfield work, and only one disadvantage. This disadvantage is due to the fact that at anything below full load, the alternating-current motor is less efficient than the direct-current motor. The slight saving in current, however, due to this characteristic, would not, generally speaking, counterbalance the increased interest and depreciation charges on the more costly direct-current plant.

The advantages of the polyphase alternating system may be broadly stated as follows: (i) Adaptability to extension over long distances and wide areas by the use of static transformers. (ii) Greater overload capacity of the motors and more rugged construction. (iii) Simplicity of control of the motors. (iv) Elimination of fire-risk, owing to there being no commutators, and the use of oil-immersed switchgear. (v) Lower first cost of plant.

The prices below, in each instance, include all necessary protective and control switchgear, and complete countershafts with pulleys.

Comparative Cost of Drilling Motors.

Motor.	Alternating Current.	Direct Current.
50 hp. ..	£180	£310
75 hp. ..	£215	£390

Prime Movers and Power-house.

As a public supply of electricity will not always be available for use on many oilfields, it is advisable to go thoroughly into the matter under this heading, as in the large majority of cases, a power-house will have to be installed before the advantages due to the use of electricity can be reaped.

As regards the cost of power, unless the price offered by the supply Co. is a very enticing one, there is no doubt that it would pay the operator to plan and erect a power-plant of his own, as he will in all probability be able to generate power considerably cheaper than he can buy it from a power Co., especially if the wells on his property give a fair amount of natural gas. Some years ago the author was able to generate power in a plant of only 750 k.v.a. capacity, using Diesel engines, at a total cost of 0·5 penny per kw. hr., although exceptionally heavy expenses had to be met for repairs. Fuel-oil for the engines was costing 40s. per ton, while the load factor was about 47 %. On most oilfields, be they large or small, having a steady day-and-night load from pumping wells, and a number of strings of drilling tools running continuously, it should be quite easy to improve this load factor.

The type and size of the prime movers to be installed at the power-house will depend upon local conditions. If there is a good supply of natural gas available, gas-engines would of course be chosen, whilst if little or no gas were available, engines of the Diesel or semi-Diesel type should be installed.

Gas-engine operation, using natural gas, is much to be preferred, both on account of the lower first cost of gas-engines compared with the cost of oil-engines, and of the fact that the fuel employed is a waste product. The slow-speed horizontal type of engine is the most suitable and reliable, in sizes of moderate power, for isolated oilfield work. With these engines having two cylinders and heavy flywheels, a cyclic regularity of 1 in 200, or even higher, can be obtained, making them quite suitable for driving alternators in parallel.

Gas-engine manufacturers usually list their engines giving the test-brake horse-power, i.e. the power the engine has worked up to on the test plate. This really represents the maximum brake horse-power, and the working power for a 12-hour day should not exceed 80 % of this figure, whilst, if the engine has to run

continuously, the load should not exceed 65 % of the maximum b.h.p.

On a small oilfield having about 60 producing wells, divided up into seven groups of eight wells each, and four wells pumped independently, with six strings of drilling tools, five of which are kept running continuously, the average load will be about as follows:

5 strings of drilling tools (averaging 20 hp. each) ..	100	hp.
7 groups of pumping wells („ 12 „) ..	84	„
4 independent pumping sets („ 8 „) ..	32	„
Machine and boiler shops	10	„
Surface pumping	20	„
Electric lighting	10	„
	256	„
Transmission-line losses 10 %	26	„
Total average load on power-house	282	„

From this it will be seen that an average load of 282 hp. will have to be carried by the power-house. If the undertaking is not likely to increase its operations, it would be advisable to install three engines, capable of giving 100 hp. each, continuously, and one of similar size as a spare, four engines in all. Should, however, there be some likelihood of the operations of the Company carrying out work on a larger scale at some future date, it would be advisable to install larger generating units in the first instance, say two engines of 150 hp. each, and one spare engine of the same size; so that, when it became necessary to carry out extensions at the power-house, there would not be a large number of generating sets.

It will be seen from the foregoing, how easy it is to provide for the centralisation of the power for any oilfield requirements, and also, the simplicity of arranging for extensions by the adding of extra units.

The exhausts from the gas-engines should be led to a waste-heat boiler, fed by water from the engine cylinder-jackets at a temperature of about 140° F. The temperature of the exhaust gas should be well over 700° F., and the power derived from this source should be about 10 % of the main engine-power. This energy could be used for driving exciters or other auxiliary plant, or, in cases where the plant is situated in desert regions, and fresh water has to be distilled for domestic purposes, this means should be employed for providing for these requirements, thus avoiding heavy capital outlay on evaporating plant, and expenses for fuel and labour for running it.

In a paper read before the Association des Ingénieurs de Liége

by Mr. Leon Greiner, some very important figures are given regarding the utilisation of waste gases from four engines installed by the Cockeril Co., aggregating 5,000 hp. The exhaust gases, leaving these engines at a temperature of 280° C., are led to four boilers (one to each engine), and are reduced in the economisers to 110° C., while the water is heated up from 8° C., to 170° C., and then converted into steam at a pressure of 114 lbs. per square inch. This steam is then supplied to a turbine developing about 650 hp.

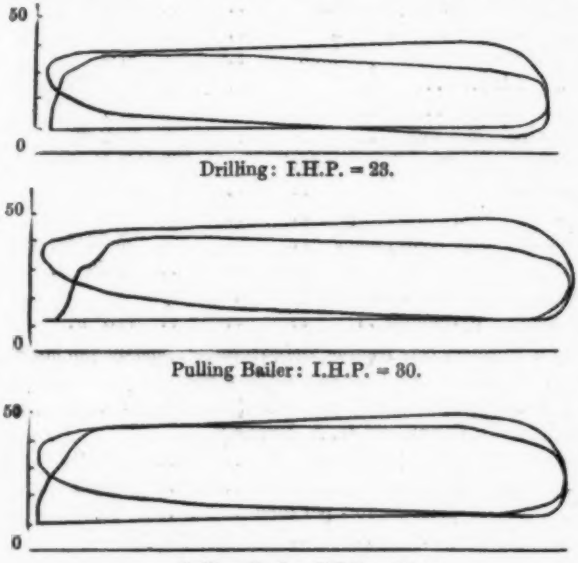

Fig. 16.—Indicator-diagrams taken by author from 12″ × 12″ drilling engine. Hole, 8″ diameter. Depth, 2,400 ft. Boiler, 400 ft. from engine. Boiler pressure, 100 lbs. per square inch. Spring, 1 : 60.

The consumption of natural gas in the main engines should be about 15 cubic feet per b.h.p. hour, so that in the plant referred to (800 hp.), 108,000 cubic feet of gas would be consumed every 24 hours. This gas should be passed through a gasoline-recovery plant, to extract the condensable vapours before going to the main engines. By this means from 200 to 500 gallons of gasoline per day can be recovered, and the income resulting from the sale of this valuable product put against the cost of power-generation.

If oil-engines are used for power-generation, the consumption of oil will be from 0·5 to 0·75 lbs. per hp. hour. The following particulars of some tests on internal-combustion engines clearly show the economy of this class of prime mover.

Test on 50 hp. Crossley Gas Engine by Professor Burstall.—(The Internal Combustion Engine. H. E. WIMPERIS.)

Size of Engine	14″ × 21″
Duration of Test	6 hrs. 45 mins.
Average revolutions per minute	166·02
„ explosions „ „	81·2
„ mean pressure per inch	91·4
„ i.h.p.	60·5
„ b.h.p.	49·7
Mechanical efficiency	82·2 %
Calorific value of gas (lower value)	578 B.T.U. per cub. ft.
Thermal efficiency on i.h.p.	37·43 %
„ „ b.h.p.	30·8 %
Water discharge from jacket	25·66 lbs. per min.
Average rise in temperature of jacket water	77·52° F.
Mean temperature of exhaust as measured by Callender pyrometer	718° F.

Test of a National Gas Engine, twin-cylinder single-acting horizontal type; working on coal gas at the Cleveland Bridge and Engineering Co. Cylinders 22″ × 30″.—(The Gas, Petrol, and Oil Engine. D. CLERK and G. A. BURLS.)

Average revolutions per minute	158·18
„ explosions „ „	63·02
„ mean pressure lbs. per inch	92·32
„ i.h.p.	334·5
„ b.h.p.	276·0
Mechanical efficiency	82·5 %
Coal gas consumed per b.h.p.	16·0 cub. ft.
Calorific value of gas (lower)	540 B.T.U. per cub. ft.
Brake thermal efficiency	29·7 %
Indicated thermal efficiency	36·0 %

Test on 300 b.h.p. four-cylinder, four-cycle Diesel Engine.—(The Diesel Engine. A. P. CHALKLEY.)

Duration of Test, hours	0·83
Revolutions per minute	402·4
Indicated horse-power	390
Brake horse-power	297·5
Mechanical efficiency	76·2

Fuel consumed per i.h.p. (excluding compressor) lb...	0·302
„ „ „ b.h.p. hr. (oil 18,000 B.T.U./lb) lb.	0·434
Quantity of cooling water per b.h.p. hr. lb.	57·4
Inlet temperature of cooling water	55·4° F.
Outlet „ „ „ „	98·8° F.
Temperature of exhaust gas	734·0° F.
Heat units consumed per i.h.p. hr.	5,470·0
„ „ „ „ b.h.p. hr.	7,800·0

Comparison of Electrical Working of an Oil Property versus Combined Steam and Gas Engine Working.

In this comparison the author proposes to take the example of a moderate sized field, having about 120 producing wells, giving a monthly production of 6,000 tons of crude oil. High-class gas-engines are principally used for pumping and general power purposes, and steam drilling plant. Sea water is used for boiler feed purposes, and distilled for domestic use by condensing boilers supplying steam to surface pumping plant, the exhaust steam therefrom being passed through a surface condenser.

The pumping wells are driven in 16 groups by 30 b.h.p. gas-engines, and by six sets of independent pumping outfits, the latter capable of being used for cleaning out operations. There are 12 strings of drilling tools, ten of which are kept running continuously. Machine shop, boiler shop, smith's shop, carpenter's shop, and electric lighting and ice plant loads are handled by gas-engines. The total average load on the power-house for an undertaking with these requirements should be 600 hp., and could well be handled by three gas-engines of 280 maximum b.h.p. A fourth engine of similar capacity should be provided as a standby.

The capital expenditure on steam- and gas-engine plant would be as follows:

Drilling Plant.

12 Cornish type drilling boilers, 300 square feet heating surface, including freight	£3,600	0	0	
12 drilling engines 12″ × 12″ ..	1,002	0	0	
12 sets of foundation blocks and sills	84	0	0	
12 boiler feed pumps	420	0	0	
12 condenser lines	780	0	0	
12 sets of separators and traps ..	120	0	0	
12 sets of tanks	240	0	0	
12 sets of steam connections ..	120	0	0	
12 sets of water, oil, and gas connections	120	0	0	
				£6,486 0 0

	Brought forward				£6,486	0 0
	Condensing and Surface Pumping Plant.					
2	30′ × 8′ Lancashire boilers and settings, including freight	£2,000	0	0		
2	boiler feed pumps	70	0	0		
4	duplex steam pumps for salt water 6″ × 4″ × 6″	120	0	0		
3	duplex steam pumps for oil, 2,500 gals. per hr.	150	0	0		
2	duplex steam cargo pumps, 40,000 gals. per hr.	600	0	0		
1	surface condenser, 5,000 lbs. steam per hr.	400	0	0		
					£3,340	0 0
	Well Pumping Plant.					
16	30 max. b.h.p. gas engines ..	£2,640	0	0		
16	sets of cooling tanks and starters	320	0	0		
6	30 max. b.h.p. gas engines and reverse clutches	1,470	0	0		
6	sets of cooling tanks and starters ..	120	0	0		
					£4,550	0 0
	General Power Requirements.					
3	30 max. b.h.p. gas engines for machine shop, boiler shop and carpenter's shop	£495	0	0		
3	sets of cooling tanks and starters ..	60	0	0		
1	40 max. b.h.p. gas engine and 20 kw. dynamo cooling tanks and starter	300	0	0		
1	lighting switchboard	20	0	0		
1	10 max. b.h.p. gas engine for ice plant with cooling tanks and starters	100	0	0		
	Total freight on all gas engines ..	935	0	0		
	Foundations for all gas engines ..	600	0	0		
					£2,510	0 0
	Total				£16,886	0 0

The capital expenditure on electrical plant would be:

POWER-HOUSE.					
4 260 max. b.h.p. gas engines ..	£4,680	0	0		
4 130 kw. generators and exciters	2,200	0	0		
1 electrically-driven air compressor	100	0	0		
1 main switchboard and connections	600	0	0		
Freight on engines and generators ..	560	0	0		
Foundations	460	0	0		
				£8,600	0 0
DRILLING PLANT.					
12 75 hp. drilling motors complete with all control gear and countershafts	£2,580	0	0		
Foundation blocks and sills	40	0	0		
Freight on motors	120	0	0		
				£2,740	0 0
CONDENSING AND SURFACE PUMPING PLANT.					
2 waste heat boilers 2,000 lbs. steam per hr. each, including freight	£700	0	0		
2 boiler feed pumps	50	0	0		
Condensing lines & circulating pump	160	0	0		
2 35 hp. 40,000 gals. per hr. centrifugal cargo pumps	250	0	0		
4 8 hp. 3" centrifugal pumps 100 gals. per min.	160	0	0		
				£1,320	0 0
WELL PUMPING PLANT.					
16 15 b.h.p. motors and switchgear	£900	0	0		
6 8—24 b.h.p. independent pumping and cleaning out sets ..	930	0	0		
Foundation sills	44	0	0		
Freight on motors	132	0	0		
				£2,006	0 0
GENERAL POWER REQUIREMENTS.					
3 15 hp. motors and switchgear for machine shop, boiler shop and carpenter's shop	£175	0	0		
1 5 hp. motor and switchgear for ice plant	30	0	0		
Foundation sills and freight ..	28	0	0		
				£233	0 0
				£14,899	0 0

We have, therefore, in order to compare the systems:

Capital expenditure on steam and gas-engine plant	£16,886	0	0
" " " electrical plant	14,899	0	0
Difference	£1,987	0	0
Add the saving in expenditure on construction of 37 workmen's dwellings at £30 per house ..	1,110	0	0
Total saving in capital expenditure in favour of electrical plant	£3,097	0	0

The cost of transmission-lines for the electrical scheme has not been included, as more than counterbalanced by the decreased cost of water, gas, and oil-fuel lines. All figures quoted for machinery, freight, etc., are pre-war prices.

Working Expenses.

Steam and Gas Engine Plant. Fuel.—Based upon actual facts, a field, similar to that now under consideration, would consume about 250 tons of crude oil per month for steam raising purposes, over and above all the gas that could be obtained from the producing wells. Taking the consumption of natural gas in the power-house engines to be as high as 15 cubic feet per b.h.p. hour, and from 80 to 100 cubic feet per hp. hour in the steam boilers, the whole of the 250 tons of crude oil per month used for fuel purposes could be saved in the case of electrical working.

If the gas consumed in the main engines were treated to extract the gasoline, and a suction put upon the producing wells to extract the gas more efficiently, a further considerable sum could be put to the credit of the electrical system.

Taking the number of b.h.p. hours per day run at the power-house as 14,400, and the gas-consumption at 15 cubic feet per b.h.p. hour, we get a total quantity of 216,000 cubic feet of gas per day for treatment. Presuming a yield of at least 2 gallons of gasoline per 1,000 cubic feet, the product would be 432 gallons per day, or 129,600 gallons per year, working 300 days. Taking this at the low value of 6d. per gallon on the field, we obtain a gross value of £3,240. Deducting running expenses, interest and depreciation charges for the gasoline plant, totalling £700, we obtain a net income of £2,540 for the undertaking. Further, taking it for granted, that, by the use of compressors to put a suction on the pumping wells and for pumping the gas to the power-house, an

Oil fuel, 3,000 tons per annum at £3 per ton	£9,000	0	0			
20 firemen at 4s. per day for 300 days	1,200	0	0			
4 firemen at 4s. per day for 365 days	292	0	0			
25 pumping power attendants at 4s. per day for 365 days	1,825	0	0			
6 attendants for independent pumping sets at 4s. per day	488	0	0			
1 pumping department power superintendent	180	0	0			
Installing and dismantling 12 steam drilling plants per annum ..	360	0	0			
Repairs to feed pumps, boilers and engines	750	0	0			
Boiler cleaning	360	0	0			
Repairs and renewals to gas engines	330	0	0			
Lubricating oil	575	0	0			
Packing and jointing material ..	200	0	0			
				£15,560	0	0
Electrical Plant.						
Fuel. Natural gas only	£0	0	0			
Power-house superintendents, 2 at £20 per month	480	0	0			
Power-house engine drivers and oilers	511	0	0			
" " renewals and repairs ..	80	0	0			
" " lubricating oil ..	384	0	0			
" " waste and general stores	10	0	0			
Firemen	0	0	0			
Pumping power attendants, 4 at 4s. per day	292	0	0			
1 pumping department power superintendent	180	0	0			
Installing and dismantling 12 drilling equipments per annum ..	24	0	0			
Repairs and renewals to motors ..	96	0	0			
				£2,107	0	0
Combined steam and gas-engine plant working expenses				£15,560	0	0
Electrical plant working expenses				2,107	0	0
Saving in favour of electrical working				£13,453	0	0

increased yield of oil was obtained, equal to 1 %, namely, 60 tons per month, at a value of £3 per ton, we have a further sum of £2,160 per annum gained.

Thus, by the centralisation of the power requirements of the field, by the use of electricity, the following gains are made:

Decreased working expenses	£13,453	0	0
Revenue from gasoline plant	2,540	0	0
Revenue from increased production	2,160	0	0
Estimated saving in time, labour and production by pulling producing wells with electric hoist ..	700	0	0
Saving in interest at 5 % on difference in capital expenditure	155	0	0
Total annual gain in favour of electric working ..	£19,008	0	0

To show that this system of working is not only advantageous on established fields, the author will take the case of an isolated prospecting outfit. The work to be carried out will be to drill four wells to an average depth of 2,200 feet, for testing a fairly extensive territory.

It is presumed that No. 1 location is about ½ a mile inland from the sea-shore on high ground. No. 2 location a ½ of a mile farther inland. No. 3 location is 3 miles inland, necessitating a haul of 10 miles from No. 2. No. 4 is 2 miles inland, necessitating first a haul of 3 miles to the coast, 9 miles transportation by sea, and a further haul of 2 miles. Sea-water is the only available water for boiler-feed purposes, and fuel-oil can be procured from an adjacent field at a cost of about 40s. per ton.

CAPITAL EXPENDITURE ON STEAM PLANT.

1 24′ × 4′ 6″ Cornish type drilling boiler	£300	0	0	
1 12″ × 12″ drilling engine	85	0	0	
1 boiler feed pump	35	0	0	
1,000′ 4″ condenser line	60	0	0	
Steam separator and trap	10	0	0	
Steam water and fuel connections ..	15	0	0	
Tanks	25	0	0	
3 miles of 2″ water line	500	0	0	
10 hp. oil engine and water pump ..	150	0	0	
1 1 kw. petrol electric lighting outfit	85	0	0	
				£1,265 0 0

Capital Expenditure on Electrical Plant.

1 80 max. b.h.p. gas engine, with vaporiser for crude oil	£500	0	0		
1 40 kw. generator and exciter ..	130	0	0		
1 switchboard and connections ..	60	0	0		
1 40 kw. transformer	75	0	0		
1 50 hp. drilling motor and switch-gear	200	0	0		
1 small boiler for distilling water ..	10	0	0		
1 motor-driven water pump	40	0	0		
3 miles 1¼" water line	225	0	0		
3 miles of transmission line no. 6 B. and S. exclusive of poles	175	0	0		
1 1 kw. lighting transformer	12	0	0		
				£1,427	0 0
Capital expenditure on electrical plant				£1,427	0 0
Capital expenditure on steam plant				1,265	0 0
Balance in favour of steam plant				£162	0 0

Working Expenses of Steam Plant.

Fuel for drilling boiler and bit forge, 1½ tons per day for 400 days, £3 per ton delivered at boiler ..	£1,800	0	0		
Fuel for water pumping engine, 400 days	175	0	0		
Fuel for electric lighting engine, 400 days	75	0	0		
2 firemen for 400 days at 4s. per day	160	0	0		
1 pumpman „ „ „ 2s. „ „	40	0	0		
Installing and dismantling steam boiler and drilling machinery at 4 wells	150	0	0		
Repairs to boiler, engines and pumps	160	0	0		
Boiler cleaning	50	0	0		
				£2,610	0 0

Working Expenses for Electrical Plant.

Fuel for generating plant, 0·75 lbs. per hp. hr. for average load of 20 hp. per hour for 24 hours per day for 400 days = 64 tons, + 136 tons for bit forge and distilling boiler = 200 tons at £2 10s. per ton delivered at power-plant	£500	0	0			
2 power-house attendants at 4s. per day, 400 days	160	0	0			
Installing generating and drilling machinery at 4 wells	100	0	0			
Repairs to machinery	25	0	0			
				£785	0	0
Interest at 5 % per annum on difference in capital expenditure				8	0	0
				£793	0	0
Working expenses for steam plant				£2,610	0	0
Working expenses for electrical plant				793	0	0
Difference				1,817	0	0
Saving in haulage of boiler, tanks, pipelines, etc...				100	0	0
Total saving in favour of electric working				£1,917	0	0

In conclusion, the author wishes to express his appreciation of the courteous way in which the Publication Bureau of the General Electric Co. of America has provided him with information and photographs in connection with their electrical outfits for oilwell operation.

APPENDIX I. POWER AND COSTS OF OPERATING OILWELLS IN CALIFORNIA.

1. Cost of Electric Power for Drilling, Power Rate Assumed 1·5 cents per kw. hr.

Depth of Well in Feet.	Cost of Power per Foot Drilled.
735	$0·1074
1,495	0·1025
945	0·0915
1,356	0·1060
824	0·0570
732	0·1040
1,175	0·0848

2. Cost of Electric Power for Pumping on Several Properties.

No. of Wells.	Average Depth.	Assumed rate per kw. hr.	Cost per Well per Day.
4	800	$0·015	$0·80
2	950	0·015	0·65
15	1,000	0·015	0·71
—	1,100	0·015	1·08
2	1,100	0·015	1·21
—	1,400	0·015	1·05
1	1,500	0·015	1·13
62	1,600	0·01	0·69
1	1,700	0·015	1·11
110	750—2,700	0·01	0·84

3. Power Required for Pumping Oilwells by Jack Rigs.

No. of Wells.	No. of Motors.	Average kw. hr. per Well per Day.	kw. hr. per Barrel Pumped.
7	1	39·7	2·52
8	1	37·6	2·30
14	1	31·9	1·41
8	1	37·1	1·67
8	1	29·1	—
8	1	30·4	—
9	1	28·2	—
12	1	26·3	—
23	1	15·7	—
22	1	17·2	1·43

APPENDIX II. RECENT DEVELOPMENTS.

According to the latest information procurable, considerable developments in the application of electric motors to oilwells have taken place since the author first drafted this paper. These tend to show the firm hold this form of power now has in the oil industry; a hold which is increasing, especially since the improved prices for crude oil have enabled operators to consider improved methods of production.

In the United States of America there are now 1,750 applications of electric motors to oilwells, aggregating 38,000 hp., principally distributed as follows:

Appalachian Oil Districts	525	motors	aggregating	5,880	hp.
California " "	850	"	"	23,100	"
Texas " "	35	"	"	625	"
Kansas " "	175	"	"	5,200	"
Louisiana " "	30	"	—	—	
Oklahoma " "	50	"	—	—	
Illinois " "	a few	"	—	—	

In California, 100 wells have been drilled by electric power, the deepest of which reached a depth of 2,700 feet, while one was taken down to 3,100 feet in West Virginia.

In Russia, it is stated that 27 % of the 11,000 wells in the Baku district are operated electrically, necessitating generating plant amounting to 70,000 kw.

Rumania has about 200 wells electrically operated, aggregating 14,000 hp.

For the past year the Burmah Oil Co. has been carrying out successful experiments with electrical motors for drilling, pumping, pulling and cleaning, in the Singu field in Upper Burma.

APPENDIX III. BIBLIOGRAPHY (CHRONOLOGICALLY ARRANGED).

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The author having ignored our precepts as to giving the no . of volumes and pages (vol. ii, p. 161), we have only been able to remedy the defect in the case of journals accessible in London. —ED.

DISCUSSION.

The Chairman, in opening the discussion, said he was quite sure all the members regretted very much that the author of such an excellent paper was not able to be present, because if he had been he would have been the recipient of many personal congratulations upon the masterly manner in which he had dealt with his subject. On the other hand, he had been fortunate in having had his paper so efficiently presented on his behalf by Mr. Holiday, to whom all the members present were greatly indebted.

The author wrote with unquestionable authority on a subject in relation to which, by training and very considerable experience, he was exceptionally well qualified to express his views, and he appeared to him (the Chairman) to have made out an unassailable case on behalf of the employment of electric power in the oilfields. There had been, as most of those present were well aware, a generally accepted opinion that, at any rate for actual drilling operations, the comparative lack of flexibility, or what might be termed elasticity, of the electric motor had restricted its use, and that this had been recognised as a drawback amounting almost, if not quite, to a disability. But in the light of what the author had stated he supposed that that view must be dismissed from their minds as no longer

tenable, and that the continued use of the admittedly wasteful steam engine must be put down to the innate conservatism of the average driller, and perhaps also to some extent to a failure on the part of those responsible to recognise the need for economy in the work. No doubt it was difficult, when one was under the stress of excitement, and witnessed a flood of petroleum being poured out from a well, to realise that there was nevertheless the same need for conservation, the same need for economy, as existed in every other sphere of industrial life in relation to which there was not the same evidence of prodigal yield by Nature.

He had endeavoured to say what he felt personally in regard to the matter, but it now became his duty to express the views of an engineering member of the Council of the Institution, Mr. Herbert Barringer, who was present for a short time at the opening of the proceedings that evening, but who had had to leave for the North on Government duty, and was therefore unable to express his views in person. Under those circumstances Mr. Barringer had requested him (the Chairman) to do so. What Mr. Barringer desired him to say on his behalf and what he would have said if he had been able to remain was that there could be in the minds of modern, up-to-date engineers no doubt whatever of the immense advantage from an economic point of view of employing electricity in oilfield operations, even including the actual drilling of the well, in respect of which, as he had already said, some considerable doubt had existed. But before electricity could be employed for the purpose, it was necessary to get it; and Mr. Barringer thought there were many cases in which, owing to the difficulty of getting the necessary supply of electricity, it might be better to make use of the wasteful steam-engine or of the internal-combustion engine. Mr. Barringer of course admitted that if the oilfield was so situated that a source of electrical power could be tapped, if there was an electrical installation within reasonable distance which could be connected with the motors, then no engineer would be in any doubt as to his duty, which would be to recommend the employment of the current. Mr. Barringer quite realised that an engineer would certainly aim at the provision of electrical power wherever it could be obtained sufficiently cheaply, and employ it for the various purposes specified by the author in his paper. Finally Mr. Barringer wished to point out that there was room, in his opinion, for a further expansion of the subject which the author had dealt with so ably in his admirable paper by specifying the various methods by which in different localities the necessary electrical power could be obtained, recognising that the ideal source of power was that

which was given by water, which, however, was not available in all cases. He hoped he had presented Mr. Barringer's views in the way that he desired to put them before the meeting, and he left it to the members who were present to comment upon them.

Mr. C. Dalley said he was particularly interested in the paper, as a great portion of his time had been occupied in furthering the objects which the author had in view when compiling the paper. He desired to say, with reference to the remarks made by the Chairman on behalf of Mr. Barringer, that the obvious economy in the use of electricity was apparent when it was borne in mind that in regard to each well operated by an individual steam boiler and steam-engine the plant must be of the maximum capacity required at the well at any time. If, on the other hand, all the boilers were merged into one large boiler, that large boiler need only then be of a size to meet the average maximum requirements, and electrical power provided a method whereby that was most conveniently and efficiently effected. He agreed with the author that on an oilfield of any size the most efficient course would appear to be the centralisation of all natural gas at one point, and the utilisation of the incondensable gas under boilers, supplying steam to a modern, up-to-date steam generating plant.

He could scarcely agree with the author's statement with regard to the thermal efficiency of a Diesel engine, and furthermore its reliability was in question as compared with a modern steam turbine or high speed reciprocating steam engine. It was generally found that the additional maintenance-charges wiped out the thermal efficiency that the Diesel engine originally provided.

There also appeared to him to be a very close parallel between the installation of electrical plant in an oilfield and the installation in a fiery coal mine in this country, and, so far as was practicable, it had been his practice to specify plant which would be passed by the Home Office authorities as suitable for fiery mines in this country to be utilised for oilfield work. In that connection he ventured to suggest that the Institution would be carrying out a very useful work if, possibly in conjunction with the Institution of Electrical Engineers, it established certain recognised standards of rules governing the design of plants and their use in oilfields.

One of the chief factors in reducing the first cost of the plant was standardisation, in order as far as possible to reduce manufacturers' development charges. As the author stated, a 50 hp. motor which was quite capable of dealing, under ordinary conditions, with a 2,000 ft. well, might also be used if a large number of wells were being pumped by a power head, a duplicate 50 hp.

motor being used for the purpose. The portable hoist required for pulling and cleaning the wells could also be operated by a 50 hp. motor, so that it would only be necessary to keep spares for that one type of motor. A 15 to 30 hp. motor could be utilised for a troublesome well which required a great deal of cleaning, and isolated motors of 5 hp. could be used which could be conveniently cleaned and pulled with a portable hoist, but the number of such motors could be reduced to a minimum in that way. That would greatly assist the electrical manufacturers, and at the same time would reduce the cost of the installation to the owners.

With regard to the author's comments on the increased production through the utilisation of electricity, if a well was being pumped by a steam-engine and it had to operate day and night, it was necessary to have a fireman on the boiler, who occasionally fell asleep. The benefits resulting from the use of electricity were graphically illustrated in a recent test of pumping equipment operating under exactly similar conditions on the same well with the steam-engine and the electrical motor adjusted to give the same number of strokes. The production of oil with the motor driving was 26 % higher than with the engine drive, that being directly attributable to the uniform speed maintained by the motor as compared with the fluctuating speed of the engine drive owing to varying steam pressure, etc. In a similar comparison an electrical drilling outfit rather more than doubled the field's average speed for steam drilling, in spite of a severe handicap due to the hole caving badly in the early stages. An interesting point in connection with that particular installation was that the motor would handle 1,000 ft. of 17 in. O.D. casing, whereas at the outside the steam-engine would not tackle more than 600 ft.

In the calculation of size of power station units for both large and small oilfields, the diversity factor and load factor would be figures of great importance when sufficient figures were available to serve as a guide, and he had hoped the author would have included in his paper his personal experiences, particularly with regard to the former. In ordinary industrial operations it was curious that the diversity factor worked out as an average of 1·6, i.e. in the case of an installation where the sum of the maxima of all the motors was 1,000 hp., the maximum power absorbed at any instant seldom exceeded 620.

He had hoped also that the author would produce some wattmeter records. One great advantage that electrical operation presented was the way in which graphic records could be taken of the actual operation. It provided also a check and a permanent

record of the drilling of the well; the meter was kept sealed, and whether the drillers worked or not, the meter did.

The successful adaptability of the electric motor to oilwell work or any other class of similar work was a foregone conclusion, provided the electrical designer took the opportunity of fully investigating the conditions required, as one of the features which gave the electrical power its flexibility was the wide limits under which electric motors could be designed to operate. With regard to the type of electric power to be utilised on an oilfield, he thought time would show that 3-phase alternating current would predominate over direct current, as was the case in most industrial applications of electricity at the present day, the single disadvantage of alternating current motors, namely, speed regulation, having been successfully overcome. The author's figures of efficiency and power factor did not do justice to alternating current motors. There was no reason why the efficiency and power factor at full, half and quarter loads should not be more closely uniform, and as a matter of fact motors were being built at the present day where the efficiency and power factor curves at full, three-quarters and half loads were practically horizontal straight lines, the efficiency being 88 at full load, 88·5 at three-quarters load and 87 at half load, with power factors of 88 at full load, 84 at three-quarters load and 76 at half load. Whilst he agreed that the single speed variable speed motor was quite suitable for drilling, yet a two-speed motor for that purpose did undoubtedly facilitate the increase of speed at which the drilling and other operations could be carried out, and even the oilwell driller, when he realised the advantages which the two speeds gave him, would have no objection to carrying out the very minor operation of changing from one speed to the other. In that connection he might mention that electrical oilwell control equipments were available absolutely fool-proof, and tolerant of practically any abuse. The author, when mentioning control equipment, presumably referred to metallic controllers. Although at the moment the matter was not receiving the attention it deserved, his own experience in the installation of electrical plant in fiery mines where a large range of speed was required, was that a liquid controller was much to be preferred, providing as it did an unlimited number of speeds. It had often been found profitable and efficient to provide the necessary cooling liquid and a small cooling radiator arrangement underground, rather than use the harsher method of control.

The paper, while very ample, did not cover all the applications of electric power to oilfield requirements, but once such a power

was available at the fields the possibilities of other useful work that could be done were enormous. He desired specially to mention the advantages electric welding outfits provided for repairs and constructional work. Bearing in mind the experience that had been obtained of electrical welding during the war, one could easily imagine what future electrical welding equipments would do on an oilfield in the way of repairs and construction. There was also the application of an electric heater to wells which were apt to clog with paraffin, a point he had rather expected the author would have mentioned, because although the application of electricity to that purpose was perhaps novel, it was exceedingly profitable. Quite a small heater would raise the temperature at the bottom of the well, and increase the output of the well very considerably. That had actually been proved in the States. He desired in conclusion to congratulate the author on his excellent paper. He was in sympathy with the author in his work, and he trusted that in the future the Institution would have the pleasure of further communications from him on this important subject, which was quite as much a hobby of Mr. Burford's as it was of his own.

Mr. R. J. Ward said that the author, most certainly, was to be congratulated for the trouble and care he had taken in preparing his paper, which would serve many useful purposes. He, however seemed to think that economy in regard to fuel has not received the attention on oilfields which it deserves. It would be admitted that, in the past days of huge gushers and fountains, managers did not stop to consider which was the cheapest method of production; their main aims being to get the oil, and as much of it as possible. Any radical change in power generation was more or less determined by the selling value of the oil, and it often occurred that when productions were high the prices of crude ruled low.

In recent times, on account of the greater demand for, and consequent rise in value of, crude oil, managers had had to reconsider the question of greater fuel economy, and this was particularly evident on the Baku field, where it received very serious attention. One firm had spent in capital outlay on oil and gas motors £25,000, and after four years' working were able to show a net economy of £66,000, which not only enabled them to amortise their capital outlay, but also made for them a saving of £41,000 for the four years' working. The great economy in fuel, in this particular instance, was due to the quantity of gas available at the well's mouth, which furnished the necessary fuel for the gas motors

installed to replace steam-engines. It might be of interest to note the following figures showing the same firm's economies:—

In 1911 with 88 bailing wells, fuel consumed for exploitation purposes was 17 % of total production: in 1912, with 42 wells, 14 %: in 1913, with from 48-52 wells, 12 %: in 1914, with the same number of wells, 6½ %: in 1915, with from 50-54 wells, 3¼ %. The same firm have also installed electric motors and of 44 wells being bailed during the period 1916–1917, the power required was obtained as follows:—

16 were bailed by oil motors:
14 by electric motors:
13 by gas motors:
1 by steam-engine.

These figures showed that attention had been and was being given to the question of fuel economy, and also that no preferential treatment has been given to any one class of motor.

The question of the most suitable method of power production was governed by what means the liquid was raised, and the condition of the well itself should also be considered.

The condition of wells that are being bailed, and whose production is governed by the proper balance of water and oil in the well were certainly controlled much better when steam was used, as the speed of raising bailers through the liquid could be regulated, and be increased after leaving the liquid.

With every kind of motor the speed of raising was more or less constant, but on account of the slower speed of oil motors they were to be preferred to electric motors, which gave a raising speed of 1,300 ft. per minute, the rapidity of which tended to draw in much sand, in consequence of which stoppages for cleaning were more frequent.

On the Baku field the electric motors varied from 80 hp. to 115 hp., the running speeds of the older type being 580 revs. per minute, whilst the later type of motors ran at 780 revs. per minute. This meant that the ratios of driving pulleys to driven pulleys were very high, causing tremendous wear and tear on the belting, also losses of production on account of stoppages due to slipping off of belting as climatic conditions changed. This latter trouble had been somewhat allayed by placing the bailing drum on rails, and by means of take-up screws any slackness in the belt could be immediately rectified.

A disadvantage of depending entirely on electricity arose from breakdowns at the generating station, when the whole production was stopped, and in some cases it took, after re-starting, consider-

able time to get the wells back to their former producing position, thus showing heavy losses on production. In Baku, however, the demand for electricity had certainly outgrown the supply of power available, and it had to be rationed very carefully; this unfortunate state of things being due to the fact that the machinery required for the extension of the generating station was sunk in the White Sea early in the war.

Actual working experience in Baku showed that for wells requiring up to 300 kw. hours a day, electric energy was certainly the cheapest power, but above that figure the oil motor began to be its greatest competitor, for, although oil motors required more labour to look after them, the small amount of fuel they consumed helped to outweigh the extra running costs.

Running expense for 100 hp. motor worked out as follows:—

Electric motor 35 roubles per day or £3 10s. at 7 kopeks or 1¾d. per unit.

Oil motor 25 roubles per day or £2 10s. with crude at 2¾d. per gallon.

Gas motor 15 roubles per day or £1 10s. using gas from wells.

The use of gas motors was, however, dependent on the amount of gas available. It should be mentioned that the initial outlay for oil and gas motors was higher than for electric motors.

In regard to the use of electric power for drilling, very good results had been obtained, but on account of the tendency to give out more work than they should, motors often burnt out. Power for the Baku fields was generated many miles from the oilfields, and transmitted at 10,000 volts to transformer stations scattered about the field, which in turn transmitted at 1,000 volts to sub-stations on each separate property, to which individual motors were connected. The current supplied was alternating. The Government allowance for fuel for power (for purposes of royalties) when using electric energy was 3 kg. of crude oil for every kw. hr. of energy used. The charge for power made by the generating Company was based on the selling price of crude oil, and since 1911 had been on basis 3·5 kopeks per kw. hr. with crude selling at 5 kopeks per pood, and an increase of 0·15 kopeks per kw. hr. for every 4 kopeks per pood rise in price of crude, plus 10 % of arrived price, which latter addition (i.e. 10 %) was deducted when more than 500,000 kw. hrs. are taken per annum. The kopek was about a halfpenny, and the pood 4·25 gallons.

The whole question of power production should be looked at from a wide point of view. Crude oil being available on the spot, there was no need to consider the consumption of fuel per hp. in

decimals of a pint, but rather what was the most suitable for each individual well, and as far as possible the different methods of generating power should be fairly divided over the whole field, so that stoppages from breakdowns should not materially affect the daily production, which is after all the daily income. The units of each separate system should be standardised as far as possible, in order to reduce the number of spare parts required, and also to make it easier for those responsible for the running of the machines. Where steam plant was available, it should not be scrapped, but held in reserve as an auxiliary in case of breakdown.

Dr. Leo Henderson said he thought the paper was one of the most complete and valuable that had been presented to the Institution. When he was in California recently the introduction of electricity into oilfield work was rapidly increasing, and it was worthy of note, when considering the importance of the subject from a public standpoint, apart from that of technology, that in the autumn of last year the Committee on Petroleum, appointed by the California State Council of Defence, issued a Report in which it recommended that, for the purpose of saving fuel oil and gasolene throughout California, products which were of enormous importance at the present time, hydro-electric energy should be substituted as far as possible for the other sources of energy at present used, and it was estimated that if that could be done, the saving would be 1½ million barrels of fuel oil, and over half a million barrels of gasolene per annum.

Mr. Cunningham Craig desired to add his tribute of praise to the very great value of the paper that had been read. The impression that the paper and discussion had made upon his mind was best expressed by a quotation of a few words from that well-known poem of Rudyard Kipling's "M. McAndrews' Hymn." Speaking of his experience with steam, McAndrews said:—

> "What I have seen since ocean steam began
> Leaves me nae doubt for the machine, but what about the man?"

It seemed to him that the problem consisted in either the education of the driller in electrical work or the education of the electrician in oil drilling. That difficulty would not be got over very quickly, and the sooner it was tackled the better.

Mr. J. C. Templeton considered the subject as having an immediate interest to every member of the profession, and being a matter of extreme practical importance to the whole operation and management of an oilfield.

He thought that the author was preferential in his treatment

of the electrical proposition, e.g. on page 233 Mr. Burford quotes from Mr. Rappoport's paper, given before this Institution in 1915, showing the increase in use of electricity on the Baku oilfields between the years 1910 and 1913. The increase was approximately 180 %, but it was a strange coincidence that it corresponds exactly with the increase in price of oil during the same period. Incidentally from the same table one could note that the increase in the number of oil engines used was approximately 270 %. From these factors, it was fair to deduce that the increase in the selling price of oil caused the officials to consider their fuel bill, with the result that the economic tendency was considerably more towards the introduction of oil engines than to the introduction of electric motors. So, from the same table, one appeared to be able to prove many things.

It was interesting to note from table 1 of Mr. Rappoport's figures the percentage of fuel used during this period, viz. :—

1910, 13·6 % : 1911, 15·3 % : 1912, 15·1 % : 1913, 15 %,

a result not altogether in accordance with what one would expect, since with practically the same number of wells drilling, viz. :—

Wells, 1910, 214 : 1913, 225 :

A reduction of steam plant in use, 1910, 2,314 ; 1913, 1,683 :

An increase in oil engines used, 1910, 240 ; 1913, 893 : and

An increase in electric motors used, 1910, 361 ; 1913, 1,002,

we have an increase in the percentage of fuel used. Many factors, however, outside of fuel economies, could account for this. Mr. Rappoport, in his table 3, also shows the relative cost of various forms of power used in Baku as follows :—

Oil engines .. .. 2·75 ;

Electric power generated locally .. .. 3·96 ;

Electric power under preferential tariff (supply Company) 4·07.

These results, so far as comparative costs go, deserve the consideration of all those who contemplate a change.

The speaker regretted very much the author's scanty treatment of the admitted non-success of some electrical installations as referable to "faultily designed installations and the prejudice of ignorant operators." The question of faulty installations, of course, could only be answered by those who designed them, but some details of where the faults lay, and the remedies applied, would have been most interesting and instructive to the industry at large. Perhaps Mr. Burford, in reply, would give us a few particulars. "The prejudice of ignorant operators" was the most important factor to be solved by those who desired to see progress made in oilfields methods. So long as the handyman element

was entrusted with the supervision of important mechanical work —and none more so than drilling or repairing wells—so long would the progress and adoption of scientific and mechanical improvements be interfered with. He would suggest that if this factor has been detrimental in the past it will also be so in the future, and therefore, as a forerunner to turning over an oilfield to electrical or any other new power, it was advisable for the Companies (British) to take out their own mechanics and train them as drillers and general field operators.

In comparing cost of the steam and electrical plant, if we separated the drilling from other work, we saw that the steam plant cost £6,488 (assuming the absence of water difficulty and therefore excluding condenser plant) as against the electrical drilling plant cost of £2,510, but to this figure must be added the portion of Power House Capital cost, viz.: £5,400 (or a total Capital cost for the electrical plant of £8,488).

It would be interesting to know how Mr. Burford accounts for the large difference between steam estimated horse-power for pumping plant and general requirements, viz. 827, and electrical horse-power for the same work, viz. 482. Surely he does not infer that this difference is one of thermal efficiency! Also whether it has been Mr. Burford's own experience that electrical drilling and pumping units do not require attendants. To me it would appear a penny-wise and pound-foolish policy to trust either to chance. A belt could break, so could a jerker line, and many things could happen to the transmission, causing loss in production or stoppage in drilling costing many times the wages of attendants.

In the case of the isolated drilling plant given, would the author explain why steam was chosen as a comparative? If we assumed internal-combustion engine drive instead of steam, the approximate cost would be as follows:—

70 b.h.p. gas engine with vaporiser plant, £500; 3 miles of water line, £825; 1 small pump, £10; 1 kw. petrol electric set, £85; 1 5 hp. oil engine pump, £100; a total of £1,010, as against an electrical plant cost of £1,427.

Mr. C. McCarthy-Jones said the paper was of considerable interest to him from a somewhat different standpoint to that of the other gentlemen who had taken part in the discussion, in that he spoke as the representative of the manufacturers of electrical equipment. He had been interested in the problems of the application of electricity to oilfields for some years, and the great advantages which the application of electricity offered to the petroleum industry had only recently begun to be appreciated. As far as a

standard cable system was concerned, with which he was chiefly acquainted, it was only since 1910 that any progress had really been made, but in California particularly, something like 2,000 electrical equipments had been installed since that date. About the same date, 1910, he had the opportunity of investigating the question, and it was perfectly obvious, even from the most superficial examination, that the economies which could be effected in oilfield working by the introduction of electricity were immense. The General Electric Company of New York, with which he was associated, took up the problem about the same time, and it was very largely due to the thorough and systematic manner in which they tackled it that the early difficulties of developing the plant necessary electrical were overcome. As the author had pointed out, motors were now offered which would practically do everything that the old steam-engine used to do, and in addition to the advantages of the steam-engine they possessed several advantages of their own, not the least of which was economy. As the paper had indicated, there were roughly two types of motor required for oilfield development, one being the drilling motor and the other the pumping motor. The difficulties connected with the development of the drilling motor, to which the Chairman had referred, and which people prophesied would be the greater, proved to be the easier of solution. The chief features of such motors were firstly the "free-fall" characteristic to which the author referred in his paper; secondly, the very close speed-regulation which was necessary, so that it was possible to arrange the speed of the beam in accord with the natural period of vibration of the line; and thirdly the very high overload capacity which the motor must have in order to deal with the exceptional cases that had to be handled, such as pulling and cleaning. All those difficulties had been successfully coped with, not without trouble in the first instance, as had been mentioned by some of the members, which might have prejudiced electrical equipment to start with. The pumping motor would be a very simple problem if it were confined to pumping work; but in practice the demand was for a motor which, in addition to pumping, would carry out the subsidiary operations of pulling and cleaning and swabbing, and even light drilling. Mr. Dalley had suggested in his remarks that it would be better to have portable hoists and small motors for pumping. No doubt that was the case, but in actual operation it was found that the drillers required one motor to do everything. The chief features of the pumping motor were the wide speed-range which could be maintained, so that low speed was available for pumping

and high speed for the other processes, and in addition there was the very high overload capacity for dealing with subsidiary work. He had had an opportunity of making a comparison between motors and the old steam-engines. Even in the case of the performance alone the advantage had been with the motor—he was not speaking of the economy but only of the performance. As Mr. Dalley mentioned, a motor was capable of handling considerably longer lengths of casing, which meant that a bigger pipe could be carried down to the oil-sand. The maintenance charges on the electrical equipment were very much less; the reliability was very much greater, and it would be found in the States that when electrical equipment was put in the insurance charges were much lower, which was a very sure indication that electrical equipments were safer for operating on the field. A great deal of attention had been recently drawn to the necessity of conserving coal in this and other countries, and the remarks which had been made in that connection applied, he thought, with even greater force to the petroleum industry. There was no doubt that so far as economy was concerned the system of steam-engines and small portable boilers and long lengths of unlagged piping was most appallingly wasteful. If the power was centralised in one spot (he did not care very much how it was obtained, whether from gas, steam, or Diesel engine plants), and was distributed to the wells, it was much more economical than the present unsatisfactory method employed in most oilfields. He welcomed the paper as an important contribution to the question under discussion.

The Chairman said that he thought a most interesting and instructive discussion had taken place upon the paper, to which the author would have the opportunity in due course of reply by transmitting to the Institution such written rejoinder as he might think fit to make. In the meantime the character of the discussion would be the best evidence the author could have of the interest the paper had aroused and the high appreciation it had received. He was sure it was the wish of those present that a cordial vote of thanks should be conveyed to the author for his paper, and that the name of Mr. Holiday should be associated with the vote for having so ably delivered it.

The resolution of thanks was carried by acclamation.

The Chairman, in closing the meeting, said that as the present meeting was the last one of the Session, it only remained for him to express the hope that the members would meet again at the beginning of the next Session with renewed energy and renewed

vigour for the prosecution of the work in which they were all jointly interested, and under happier auspices in regard to the war.

Mr. M. A. Ockenden subsequently wrote as follows :—

When visiting oilfields in the United States 18 months ago I made special inquiries with regard to electrically-driven oilfield equipment. In the Cushing field, a new yet extensive field, there was no information available with regard to drilling, as it was then stated that the tests did not justify the use of electricity for drilling. On the other hand, very satisfactory results were obtained with regard to swabbing, pumping and pulling by electricity. The best and latest methods are used in this important field.

It would be particularly interesting to have detailed results on record of fishing operations with only electrical power available. The author's comparisons of costs seem to be drawn with the use of assumed figures. Electricity for pumping purposes is satisfactory, but it will take years to demonstrate the superiority of electricity for drilling operations (which includes fishing and the handling of casing). Very rarely two wells can be drilled at the same cost, in the same time, and with the same casing, even if the geological and local conditions are identical, but this does not apply to pumping. There is much in favour of electric power in the production of petroleum in proved fields such as Burma, Peru, Russia and Rumania, but one should hesitate to recommend the use of electricity in the prospecting stage, where conditions are practically unknown.

There is undoubtedly a great opening at the present time for young engineers, and it is to be hoped that they will take up the study of electricity seriously, and record the advantages and disadvantages in the different countries, particularly the use with different systems of drilling machinery and quality of labour engaged.

The author appears to regard the rotary system as ideal for electrical power, but to prove this it would be necessary to show a series of boring logs of actual work in different fields and depths, especially with difficult casing operations. For straightforward rotary work, which can only apply to a few selected districts, electricity might now be desirable. As the author has merely referred to the use of electricity on well-known fields, it is not fair to draw a hasty conclusion that electricity is superior to steam for prospecting and oilfield work generally, although eventually it is to be hoped that it will be adopted to a larger extent.

The paper is a valuable addition to the Institution's records.

Mr. Arthur Millar writes as follows:—

Mr. Burford's paper on the application of electrical power to oil-wells must have been heartily welcomed by all those interested in the improvement and economy of oilfield engineering. The problem of the use of electrical energy, although far from new, has, on a large number of fields, been only tentatively touched upon, so that the prejudices of those using the older steam appliances have triumphed. The increasing depths to which drilling will undoubtedly have to be carried in order to tap other horizons after the exhaustion of strata at present productive, will provide much scope for the introduction of electric power for drilling and pumping processes, but nevertheless little difficulty should be experienced in its adaptation. The provision of a heavy flywheel to store momentum, and absorb shocks during casing-manipulation, where long strings such as 4,000 feet and over are in use, would appear to be absolutely necessary, as also during drilling with standard percussion rigs. The method of oil raising by swabbing in use on the Boryslaw-Tustanowice wells, mentioned by Mr. Burford, is one which would appear eminently suitable for electric motor drive, if a means of braking during the downward run is provided, as band brakes, however lined, are liable to cause firing, more especially as they are usually covered with oil. There would appear to be a possibility here of a regenerative process. Totally-enclosed motors would undoubtedly have to be used in many cases to preclude oil or water, either or both of which are present usually in copious quantities. Unless the wires are led through tubing, insulation not susceptible to oil would also appear to be necessary.

During the discussion, after the reading of the paper an objection was raised referring to the source of power being in one building and liable to breakdown thus causing a total cessation of work throughout the property. This has for long been the slogan of the anti-electrical party, and carries little weight, if the power-station is efficiently designed with a reasonable amount of standby machinery. Another point raised was the possibility of a motor fusing. This would only occur where insufficient precautions were taken in wiring: safety or blow-fuses properly installed will obviate in almost every case the possibility of serious damage being done, although the fuses themselves should be placed in a gas-tight box. A ring main system with fuse-controlled feeders will usually prevent any serious shut-down occurring in the case of fire or other accidents of a local nature.

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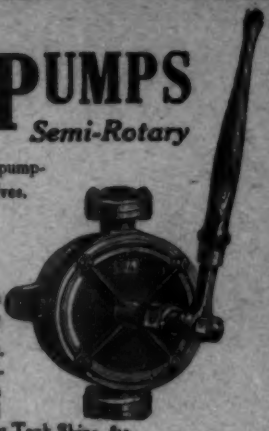

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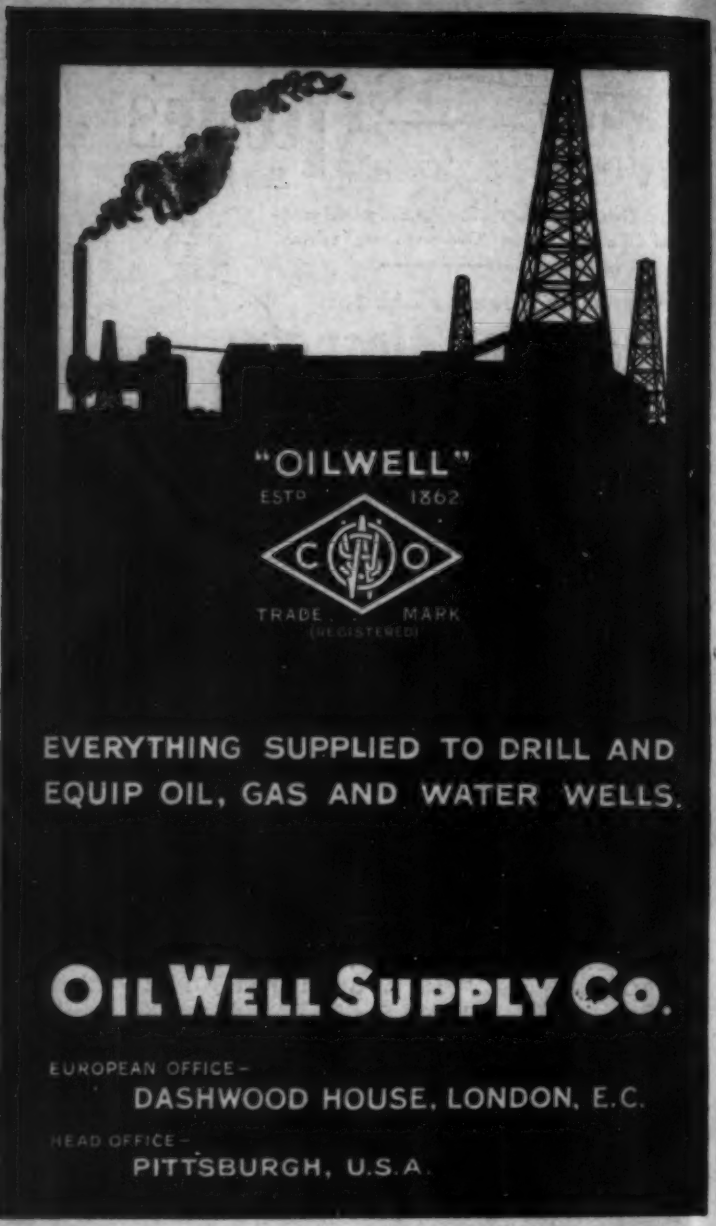
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